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IMPROVEMENT OF JANUS TARGET ACQUISITION USING A FUZZY LOGIC HUMAN FACTORS MODEL

by

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I. INTRODUCTION

A. JANUS COMBAT SIMULATION SYSTEM

JANUS is an Army-sponsored computer-based ground combat simulation system used for combat development and training. JANUS (A) is the most recent version of this system. It is an interactive, event-driven, two-sided, high-resolution ground combat simulator capable of simulating force levels from the individual soldier to division-sized units. The participants in the simulations, called "players," control opposing forces, Blue or Red, from computer terminals by establishing or changing unit routes on a computer-generated map. Players can issue limited orders that provide fire support and place obstacles.

JANUS (A) is an event-driven simulation system. This means that the simulation is updated asynchronously, as events occur, not at predetermined intervals by a master simulation clock, though a clock is used to track the simulated time of exercise and to update the simulation if no events have occurred in a given time. The system allows only two opposing forces per simulation, the Blue and Red forces, though each force may have up to 600 combat systems per simulation. [Ref. 1]

Primarily a ground combat simulator, JANUS (A) allows a maximum of 25 combat system types and 25 weapon system types per force per simulation. These forces can include ground maneuver or artillery units, engineer support, and resupply units. Included in the engineer support units is the ability to lay minefields, with up to 10 different types of mines and five types of dispensers simulated. Minefield breaching also is simulated, along with obstacles, such as ditches, abatis, and craters.

JANUS (A) has the capability to include limited air units, both fixed and rotary wing. These air units simulate air-to-ground missions only, with no air-to-air capability provided.

Each combat system in JANUS (A) is defined in a data table by entries such as weight, movement rate, sensors, etc. Because of the way they are defined in the data table, new

combat systems can be added via a new set of table entries for that system. This allows a specific using activity to simulate systems pertinent to its training needs while maintaining commonality of the interfaces [Ref. 1]. Hence, training exercises conducted at one installation can be replayed or reviewed at other installations without the need for additional training in the use of JANUS (A). This system flexibility also enables the use of the JANUS (A) system for combat development, as new unit types can be entered and can interact with previously-defined unit types through the simulator.

JANUS (A) simulations are conducted over terrain that is a digitized description of a portion of real-world terrain, with a resolution of 100 meters horizontally and 10 meters vertically. For a simulation run the terrain is divided into a square of 600x600 grid cells. These grid cells can be initialized as 25x25, 50x50, 100x100, or 200x200 meter sizes. Included in this terrain database are natural and cultural features such as various soil types (for modeling dust clouds), roads, vegetation, rivers, and buildings. Vegetation and man-made structures are not modeled as individual trees or buildings but as grid cells of buildings or of a particular type of vegetation. [Ref. 1]

The JANUS (A) conflict model is a stochastic attrition model using line-of-sight calculations and acquisition of enemy targets within the terrain database for automatic or scenario-dependent engagements. Both direct fire and indirect fire engagements are supported. Ballistic calculations are not performed for determination of an engagement's success. Direct fire results are determined by predetermined data sets for probability of kill, P_k, and probability of hit, P_h, for each weapon-target combination. These data sets are functions of several variables such as range, target movement, target orientation, etc. Indirect fire results are determined using probability dispersions for round-to-round aim and dispersion errors, which are functions of target range, and target vulnerability, which is a function of target posture or exposure. For every engagement each shot fired is evaluated and a determination as to hit and kill outcomes is calculated. There is no partial kill capability; if a target is hit it is either killed or not; if not, its systems are not degraded in any way. Firing is subject to ammunition availability and supply constraints. [Ref. 1]

B. HUMAN FACTORS SIMULATION

1. Human Factors Research

Human factors research has been conducted for many years, but it was not until the time of World War II that it held much interest outside academic circles.The size and scope of that conflict and the increasing complexity of the machines that became commonplace during the war saw a demand for research about the way human operators worked. Research topics included the attention span of radar operators, the best methods for pilot selection, the effects of various climates and protective clothing on human performance, and the factors affecting combat decision making.

After the war human factors research was continued, though the interests shifted largely to commercial applications. Some research was still conducted for the military services but most dealt with factors influencing reliability, particularly where nuclear weapons were concerned. Most of the civilian research has been concentrated in the areas of production efficiency and worker productivity [Ref. 2]. More recently this research has focused on human-machine interfacing and on human-efficient machine design, particularly as the machines in commercial and military use gain more ability and power and human monitoring requirements have increased. This change to a monitoring role instead of a more active role has been the subject of much human factors research.

Other human factors problems encountered in both the civilian and military sectors are those of task complexity, information overload, and information accessibility [Ref. 3]. The fact that all required information for a task is available is of little use if it can not be accessed at the needed time or if it is difficult to retrieve or understand it. For example, in modern combat aircraft it does no good to have a large number of sophisticated capabilities if these require the pilot to concentrate on selecting the needed capability while ignoring ground avoidance task, causing the aircraft to fly into the ground.

2. Human Factors in Combat Simulations

The simulation of military vehicles and combat scenarios has been increasing in importance over the last two decades. The reasons for this increase include the lower cost of simulation over live training, the ability to practice tasks that are to dangerous to attempt with real vehicles, and the ability to practice and improve combat tactics without the need for actual combat or large scale wargames.

Until recently the fidelity and complexity of combat simulations was limited by the computational capacity and speed of the computers that drive and update the simulations. Today that problem, while still present to some extent, is rapidly becoming less of a bottleneck. This allows the addition of more complex features and higher-resolution models in these simulations while still operating in near real time. Generally this increase in capacity has been used to model additional environmental factors, such as changing or adverse weather, or to increase the accuracy of modeled features, such as higher resolution graphics or more complex and realistic ballistic or motion equations.

An area that had not seen much work in the military simulation arena was human factors simulation. This includes such functions as human reliability and performance, incorporation and behavior of computer-controlled forces, and distributed human command and control of forces. Recent progress in computer computational power and the resultant increases in functionality have made human factors modeling more practical and more common. Distributed control problems have recently become more critical and much work is being done in this area. Interest and investment in the incorporation and behavior of computer-controlled forces, often termed semi-autonomous forces, has increased. The ability to operate a large simulation without requiring each unit to have a human commander greatly increases the availability and functionality of the simulation [Ref. 4].

Human reliability and performance have received less attention. This is partly because the exact factors involved and the relative importance of these factors have not been established to the same degree as is available for physical factors. It is common to find models of vehicle dynamics that are well established and accurate; it is unusual to find

models of human dynamics on which a majority of behavioral or psychological researchers or scientists agree. This lack of an established human performance model, along with the relative ease of improving other areas of simulation, have resulted in a minimum of research into the inclusion of human factors in simulators.

3. Fuzzy Logic in Human Factors

Fuzzy logic, as established by L. A. Zadeh in 1965, is a multi-valued logic approach for representing imprecise knowledge [Ref. 5]. This representation is especially useful for human reasoning, which is commonly done using vague or ambiguous concepts and ideas such as “tall” or “hot” which have varying meanings depending on the user and the situation. Fuzzy sets are generalizations of the notion of classical or binary sets. In classical sets an element is either in the set or it is not in the set. In a fuzzy set, an element may have varying degrees of membership in a set. It may be partially in a set and partially not in the set.

The fuzzy set method of dealing with vague concepts fits well with the current state of human factors knowledge. The many possible meanings for common descriptions of human behavior and the individualistic results often found in human factors research make the fuzzy set representation well-fitted for the task of simulating human factors. As discussed in Chapter II, fuzzy logic controllers have been successfully employed in a variety of tasks, from stock market prediction to subway control, so the validity of the logic has already been empirically proven [Ref. 5].

C. JANUS (A) TARGET ACQUISITION MODEL

The current JANUS (A) target acquisition model is based on a search model developed by the Army Center for Night Vision and Electro-optic Research. The model is implemented with computational speed as the major priority rather than an accurate representation of human target acquisition. The model computes the single-glimpse probability of detection for a sensor/target pair for each search cycle, based on the number of resolvable cycles across the target. The number of resolvable cycles is defined in the

search model to be the number of alternating light and dark horizontal bands across the minimum presented area of the target that can be distinguished at the target's distance. Search model implementation is divided into three distinct parts: initialization, potential target determination, and detection resolution. [Ref. 1]

1. Model Initialization

Initialization of the JANUS (A) search model involves the completion of several data entry and computational tasks whose results are stored as look-up tables. The tables then are used during the simulation to speed up the target acquisition process. The players each input a target list cycle time and a detection cycle time for their forces. The initialization process uses these inputs to determine how often the search function is called (the detection cycle time) and how often each unit is processed for potential targets (the target list cycle time). Several tables are also produced for each optical sensor-target pair in the simulation. These tables use various environmental factors to determine atmospheric attenuation versus range data for the sensors. These tables also are used during the target detection phase to minimize computation time.

Another table, also created during initialization, stores the number of resolvable cycles for each sensor-target pair, computed over the distribution of resolvable cycles for the sensor-target pair, and divided into intervals of 100 units. This table represents the number of resolvable cycles required for an observer at the sensor to detect the target, at any range from a minimum range (10 meters in JANUS (A)) to the sensor's maximum range, given an infinite amount of search time.

After the resolvable cycles table is created a random number is generated, over the range [1-100]. This number is used to obtain a threshold value of resolvable cycles for the sensor-target pair by using the number as a look-up index into the just-created table of resolvable cycles. This random number of resolvable cycles is used to determine whether the target is eligible for inclusion on the potential targets list. The resulting randomness is used to simulate the unpredictable behavior of different human sensor operators. For each

detection cycle that the sensor-target pair is checked, the single-glimpse number of resolvable cycles for the target at that time is compared to this random number of resolvable cycles. If the current value is greater than or equal to this threshold value, the target may be added to the potential target list for the sensor, depending on line of sight and other environmental restrictions. If the current number of resolvable cycles across the target is less than this threshold, the target is not considered further for inclusion on the potential target list for this search cycle. This threshold number is generated only during the initialization phase and is not changed for the remainder of the current simulation. [Ref. 1]

2. Potential Target Determination

After initialization is complete, the simulation begins and the second part of the model becomes active. This is the determination of a potential target list, which is done every time the Search function is called. Not every sensor is checked during each search cycle but all are checked within approximately the time specified by the potential target list cycle time, as input by the players. At the present time only 10 targets may be on this list at once. These are the 10 best possibilities for detection for the current cycle, as determined by the current number of resolvable cycles.

Before a target is placed on the potential target list of a sensor it must first pass several tests. It must not be a friendly unit, it must not be dead nor can it be mounted inside another unit (such as infantry in a personnel carrier), it must be in the sensor's field of view, it must be in the sensor's line of sight, and it must have a number of resolvable cycles, at its current range from the sensor, which is greater than or equal to the threshold for the particular sensor-target pair, as described above. The friendly status of the possible target is known to the simulation; the sensor does not need to determine this. It is possible to simulate the need for an observer to determine the friendly status of any possible target by requiring a greater degree of precision prior to detection, as will be shown later.

Targets themselves are tested for status such as dead or mounted inside another unit and for the probability that they are in the sensor's field of view. This later process is

done by dividing the sensor field of view by the sensor view fan (the sensor's area of interest as defined by the owning player or 360 degrees if the sensor is moving) and comparing this number to a randomly-generated number in the range [1-100]. If the random number is greater than the product, the target is considered to be in the sensor's field of view.

The path between the sensor and the target is checked for terrain obstructions, that is, for terrain with a higher elevation than the elevation of the sensor-to-target path at the obstruction's position along this path. The simulation also checks for trees or buildings along this path and, if they are present, their elevation is checked the same way terrain obstructions are. If the path is obstructed, the density of the obstructions (predetermined for the simulation run) is used to find a probability of line of sight through them. This is done via a look-up table of density versus obstruction type. This probability is multiplied by the number of resolvable cycles to produce a new, larger number of resolvable cycles. If line of sight is established with respect to terrain and obstructions, then the effects of large area smoke clouds, if present, are determined. [Ref. 1]

Finally, the currently-calculated number of resolvable cycles is compared to the threshold number, as defined above, for the sensor-target pair. If the current number is greater than the threshold, the target is placed on the potential target list.

As mentioned earlier, the degree of precision required for detection can be changed by the players to require a larger number of current resolvable cycles for inclusion on the potential target list. This is done by scaling the threshold number of resolvable cycles for the sensor-target pair by multiplying it by a scaling factor that represents the desired degree of precision. This scaling procedure is used to simulate various rules of engagement, such as a requirement to identify the exact model of a target (e.g., T-72 versus T-62 tank) prior to engaging the target with direct fire. Currently four different levels of precision are supported.

- *Detection*, scaled to 0.75, the lowest level of precision. For this study detection defined as "Sensing that an object that is foreign to the background is in the sensor's field of view (FOV) and should be further examined to determine if it is a target of military interest. The object may have been visible before detection, but was not distinguishable enough from other objects to trigger the inspection decision. The observer now takes whatever action is necessary to inspect the object (e.g., rotate the sensor, change to narrow FOV)."
- *Aimpoint*, the default setting, scaled to 2.0, defined as "Selecting a portion of the observed scene as a potential target and a specific point at which to aim. The observer begins to move his weapon into attack position."
- *Recognition*, scaled to 3.0, defined as "Selecting a particular spot in the scene as the target on the basis of characteristics of shape, coupled with categorizing a military target class, such as a vehicle (or, if the class is taken to be more specific, a tank, truck, or APC). The level of detail for recognition depends on the operational situation and on pre-briefing. The observer now begins attack mode, including possibly designation of the object "
- *Identification*, scaled to 6.0, defined as "Recognizing that the military target is in a specific subclass (e.g., tank) or is a specific member of a class (e.g., T-72 rather than a T-62). The subclasses are dependent on classes, the operational situation, and pre-briefing. The observer continues preparation for attack and commits to weapon firing or release." [Ref. 7]

3. Detection Determination

The third part of the target acquisition process is the determination of actual detection of a target by a sensor. Because the detection cycle may occur more frequently than the potential target list is updated, the detection process includes many of the same tests as used for potential target list determination. For each sensor with potential targets, the simulation checks whether the potential targets in its list are now dead, have mounted other units, or are already detected. If they are already detected they are not processed again, though line of sight is checked again. If dead or mounted, they are removed from the potential target list. After these tests are completed, the remaining potential targets are checked for obstructions to the line of sight and sensor field of view probabilities, as described above. These probabilities are then multiplied by the current resolvable cycles, as determined by the sensor-target table described in the initialization section, and this product is compared to a randomly-generated number. If the product is matched or

exceeded by the random number then large area smoke line of sight is tested. If this also is satisfied then the target is marked as detected.

The detection phase of the JANUS (A) simulation is critical. It determines whether a sensor can see a target and thus whether the weapon system associated with the sensor will engage it. If detected, all targets are automatically engaged by direct fire, if possible, unless the player takes the action to command the unit to hold fire. [Ref. 1]

4. Realistic Modeling of Target Acquisition

Because the engaging of opposing forces is the major goal of combat simulations such as JANUS (A), and because in JANUS (A) this process is governed by the target acquisition computations of the simulator, it is important to the realism (and therefore usefulness) of the simulation to model this process as accurately as equipment capacity allows. The present system described above is based strictly on the physical modelling of the JANUS (A) environment. The incorporation of user-definable human factors effects is needed to increase system realism. The human factors of target acquisition are currently modelled using random numbers alone. Yet human behavior and its effect on combat performance is much more complex than that. The addition of a fuzzy logic-based model of human performance to the JANUS (A) target acquisition process might provide the needed increase in simulation realism.

D. GOALS

The goal of this study is to provide an improved model of target acquisition that includes human factors that may affect the ability of an observer to detect and identify targets. The model is based on data collected from questionnaires provided to subject matter experts, Army and Marine Corps personnel taking part in an evaluation exercise requiring the acquisition and identification of ground targets. A fuzzy logic approach has been used for the reasons discussed above. The Army's JANUS (A) combat simulation system is the proposed vehicle for testing and incorporation of the proposed model. This

research into human factors effects and fuzzy logic has resulted in a prototype computer program demonstrating the new model.

E. ASSUMPTIONS

Three assumptions are made in this study.

- Human factors, such as those described above, affect combat performance.
- Incorporation of these human factors into the JANUS (A) simulation system is a desired and beneficial change.
- Data collected for this study is representative of combat in general.

There is a body of research that supports the first assumption but there is no agreed-upon theory concrning which factors are important and to what extent they affect performance. The factors proposed in this study are considered to have a major effect on human performance in a combat environment. That these factors may not be correct or complete is accounted for in the design of the prototype implementation. Though further research may yield more evidence as to what is a significant factor and what is not, the user of the simulation will still remain the final judge of which factors should be used.

The second assumption, that the incorporation of these human factors into the JANUS (A) simulation system is a desired and beneficial change, is mostly determined, again, by the end users' judgement. As the testing of this model in actual JANUS (A) simulations is not possible at the present time, the benefit of this fusion of human factors with the current JANUS (A) system is uncertain. However, without the incorporation of human factors the simulation of combat can not be realistically portrayed, at least at the large unit level. This is believed true due to the evidence of the past, where numerically, technically, and logistically inferior military units have triumphed over their superior foes. As this cannot be explained by the combatants physical capabilities, there must be human performance factors which profoundly influence he execution of individual and unit battles.

A third assumption, (less important from the viewpoint of this study) is that the data collected, as discussed later, is representative of a majority of combat situations and personnel performance. The sample size is relatively small, and the personnel sampled are

all highly trained, career-oriented Army personnel. Thus the data collected may not be representative of the military in general, or of the Army in particular.

F. SCOPE

The scope of this thesis is limited to the collection of the opinions of subject matter experts and prototyping of the resulting data into a model, using fuzzy logic. Validation of the human factors used in this model is not within this scope. However testing of the prototype program for correct operation within the limits of the collected data is included.

II. PROPOSED FUZZY LOGIC MODEL FOR TARGET ACQUISITION

A. FUZZY SET THEORY

1. Overview

The concepts of fuzzy sets and fuzzy logic were established in 1965 by L. A. Zadeh [Ref. 8]. These concepts have been expanded by others and have been used for practical applications that include camera focusing mechanisms and stock trading.

Classical set theory and fuzzy set theory differ in many ways yet at the same time they are much the same. The two theories are similar in that both operate with sets of elements, numbers, objects, or symbols. Both attempt to define groupings of similar elements. They differ in how they define these groupings.

In classical set theory, the universe of discourse is divided into two categories: that which contains the elements of a set and that which does not, a strictly binary grouping. All operations on sets depend on the fact that an element of the universe is wholly in either one or the other of these two categories. In fuzzy set theory, elements have varying degrees of membership in their associated sets. An element may be partially in one set, and partially in another set also. In other words, the degree of membership of an element may be other than the 0 (not a member of the set) or 1 (a member of the set) of classical set theory.

Moreover the total membership values of the elements of a fuzzy set need not, and in fact rarely do, add to 1.0. Neither does the sum of an element's degrees of belonging to a pair of sets necessarily equal 1.0. This allows fuzzy sets to represent vague ideas such as tall or hot without imposing an arbitrary bound on them.

As an example, one or two grains of sand are not usually considered a pile of sand, whereas 100 million grains might be considered a pile of sand. How then does one describe 800, 036 grains of sand? Is it or is it not a pile of sand? In classical set theory one

would have to assign an arbitrary bound to the meaning of "pile of sand," say, greater than 10 million grains is a pile but one grain less than 10 million is not. This would mean the 800,036 grains of sand would not be a pile of sand even though it may be a considerable amount of sand. On the other hand, fuzzy set theory is able to deal with such vague concepts by giving elements of the universe of discourse degrees of belonging to each of the sets, that is, to being a pile of sand or not. With this type of concept one could say that 10 million grains of sand might have a membership of 1.0 in the set of piles of sand, whereas the 800,036 grains might have a membership degree of only 0.1 in the set of piles of sand. [Ref. 8]

2. Membership Functions

In classical set theory all elements of a set have a membership value of 1.0, else they would not be elements of the set. In fuzzy set theory this type of set is referred to as a "crisp set." Such a set has no explicit membership values. Instead, it has implicit membership values of 1.0 for each element.

In fuzzy set theory, as noted above, elements of a set have varying degrees of belonging to a particular set. The degree to which an element of a particular universe belongs to a set is called the element's membership value. This degree of belonging is expressed as a real number on the interval [0, 1]. A standard means of representing this membership value is the following.

$$\{\text{degree of membership / element} \ldots\}. \tag{2.1}$$

In this representation the slash symbol (/) does not represent standard arithmetic division but is only a means of separation between the membership value and the element. An example fuzzy set for a concept such as *small number* (called a linguistic variable), where the universe of discourse is the set of integers from 0 to 5, might look something like this.

$$\textit{small number} = \{(1/0), (0.8/1), (0.5/2), (0.2/3), (0/4), (0/5)\}. \tag{2.2}$$

In this fuzzy set the membership of the number 0 in the set of *small numbers* is determined to be 1.0, meaning that 0 is wholly in this set. The number 1 has a membership value of 0.8 in the set, meaning it is mostly in the set of *small numbers* and partially not in this set. The number 3 is only 0.2 in the set of *small numbers*, that is, that it is slightly a *small number*, while the numbers 4 and 5 have membership values of 0 showing that they are not *small numbers* at all.

The membership values of the elements of a set must be determined by the designer or user of the fuzzy set, by defining membership functions for the set. This may be done from available data or it may be an intuitive process. The method is not important, and the functions can be changed if needed, as long as they correctly model the set under consideration as it relates to the problem to be solved. These membership functions can have several shapes. Normally they are in one of several more-or-less standard shapes: curved functions (something like a bell shape), straight line triangular functions, or straight line trapezoidal functions [Ref. 9]. Figures 2.1, 2.2, and 2.3 will illustrate the differences between these membership functions.

a. Curved Membership Functions

In Figure 1 the example sets have been plotted using bell-shaped membership functions, on a base scale ranging from 1 to 5. One method of defining the membership functions for linguistic variables such as *small, medium*, and *big* is as follows.

$$S\ (x;a,b,c) \begin{cases} 0 & x \le a \\ 2\left(\dfrac{x-a}{b-a}\right)^2 & a < x \le c \\ 1-2\left(\dfrac{x-b}{b-a}\right)^2 & c < x \le b \\ 1 & x \ge b \end{cases} \tag{2.3}$$

$$\text{membership } u(x) = \begin{cases} S(x;(b-c),(b-c/2),b) & x \le b \\ 1-S(x;b,(b+c/2),(b+c)) & x \ge b \end{cases}$$

where:

a = point where membership = 0 (lower bound)

b = point where membership is 1

c = point = $(b+a)/2$

x = point where membership value is to be determined.

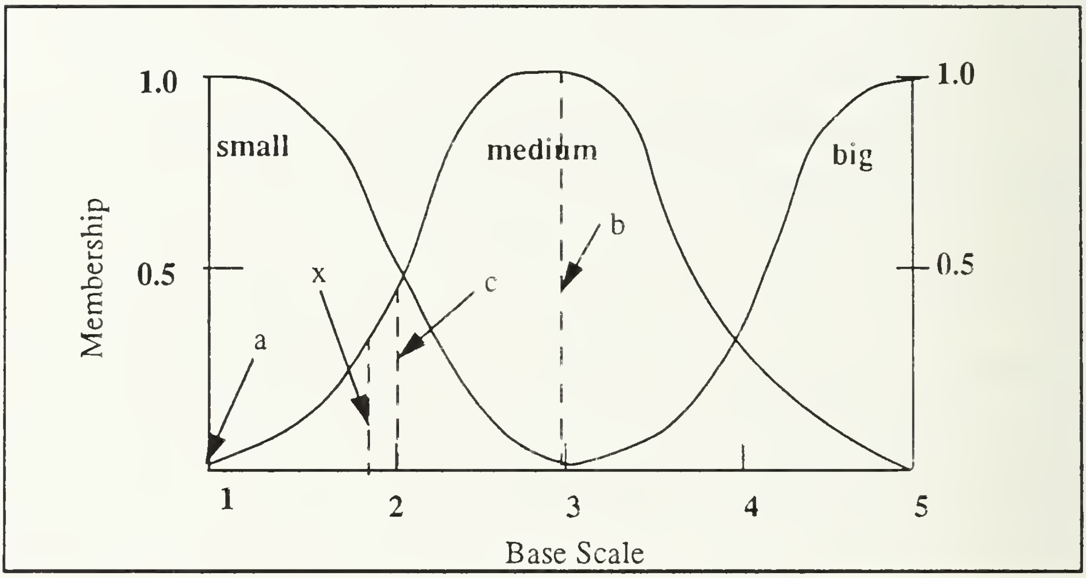

Figure 1: Bell-shaped Membership Function

b. Straight Line Triangular Membership Functions

As shown in Figure 2, the example sets have been plotted using straight line triangular membership functions, on the same base scale of 1 to 5. The membership function for the linguistic variables *small, medium*, and *big* may be defined as follows.

$$\text{membership } u(x) = \begin{cases} 0 & x \leq a \\ (x-a)/(b-a) & a \leq x \leq b \\ (c-x)/(c-b) & b \leq x \leq c \\ 0 & x \geq c \end{cases} \qquad (2.4)$$

where:

a = point where membership = 0 (lower bound)

b = point where membership is 1

c = point where membership = 0 (upper bound)

x = point where membership value is to be determined.

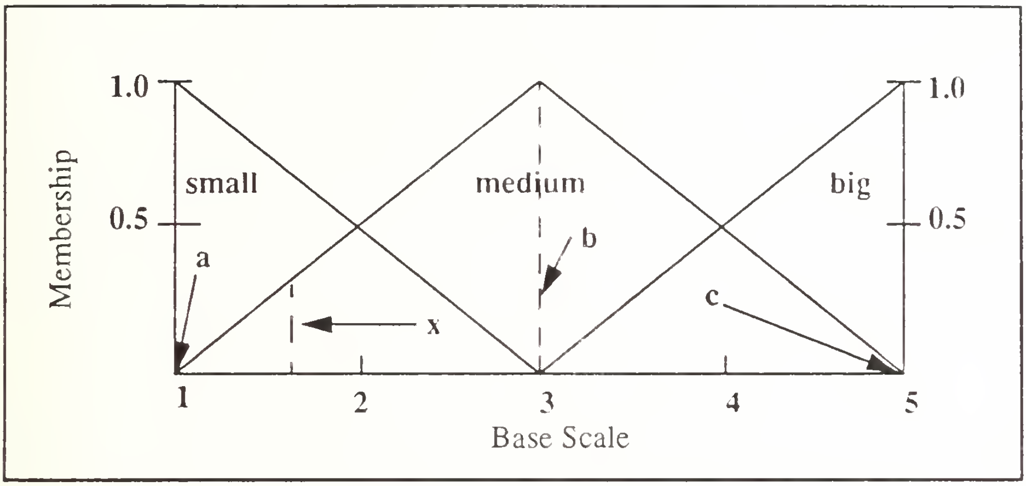

Figure 2: Straight Line Triangular Membership Function

For incomplete triangular membership functions, the same method is used with the appropriate part of the membership function. Generally straight line triangular membership functions are preferred for fuzzy control applications due to the simplified notation and the simpler computation of membership values that is possible, as can be seen above. [Ref. 9]

c. *Straight Line Trapezoidal Membership Functions*

The straight line trapezoidal membership functions are similar to the triangular membership functions. However the peak membership value extends over more than one element of the set.

$$\text{membership u(x)} \begin{cases} 0 & x < a \\ (x-a)/(b-a) & a \le x < b \\ 1 & b \le x \le c \\ (c-x)/(d-c) & c < x \le d \\ 0 & x > d \end{cases} \tag{2.5}$$

where:

a = point where membership = 0 (lower bound)
b = 1st point where membership is 1
c = $2nd$ point where membership is 1
d = point where membership = 0 (upper bound)
x = point where membership value is to be determined.

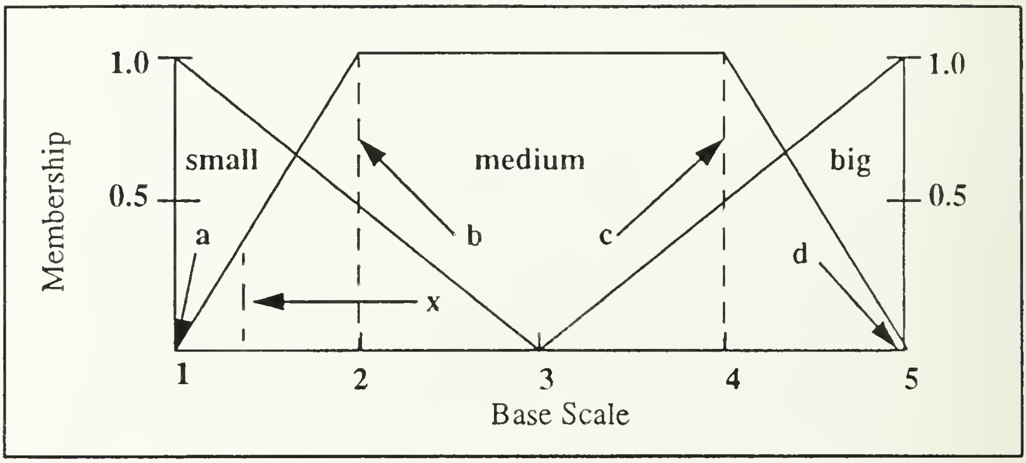

Figure 3: Straight Line Trapezoidal Membership Function

3. Fuzzy Model Construction

Several steps must be followed prior to converting linguistic or numeric variables to a fuzzy set. First, the *base linguistic variables* must be established. These may be context dependent, such as *hot, medium*, and *cold* for temperature, or they may be context independent, such as *big, medium*, or *small* for a general application. The choice is arbitrary as long as it accomplishes a division of linguistic meanings appropriate for the application.

Next the *base scale* for each fuzzy set must be determined. This is the number of elements to be found in a given fuzzy set, and may consist of integers or real numbers. The scale is determined by the designer with the only limitation being a need for at least one element for each base variable. Common base scales have values from -6.0 to +6.0, -1.0 to +1.0, or 0.0 to +1.0. In the last two examples, the scale consists of real numbers. The first scale, -6.0 to +6.0, could be either an integer or real based scale. Two general guidelines for specifying the number of base scale elements are

- The number of base scale elements should be greater than the number of base linguistic variables.
- The number of elements should be small enough to run the computations required in a reasonable amount of time, depending on the application.

After the base scale is determined, the set of elements that have non-zero degrees of membership must be determined for each linguistic variable. That is, the "meaning" of each linguistic variable is distributed over several base scale elements, as appropriate, to account for the ambiguity of the linguistic variable. Usually at least one element is chosen for each linguistic variable to represent the value or values that are central and totally encompassed by that linguistic variable [Ref. 9].

For example, assume the linguistic variables to be used were determined to be *small, medium*, and *big* and that the base scale is from 1 to 7. The center point for the linguistic variable *small* might reasonably be placed at 1, the center point for *medium* at 4, and the center point for *big* at 7. The variables can be distributed evenly across the base scale by dividing the number of base scale elements by the number of variables and using the ceiling or floor functions to determine the appropriate number.

Ceiling refers to the smallest integer greater than the quotient of the above division; for example, the ceiling of 7 divided by 3 is 3, because 3 is the smallest integer greater then the quotient of 7 divided by 3, which is 2.33. *Floor* refers to the greatest integer not larger than the quotient of the above division; for example the floor of 7 divided by 3 is 2, because 2 is the greatest integer that is not larger than the quotient of 7 divided by 3, which again is 2.33. In the above example the number of non-zero elements could be found by dividing 7 (the number of base scale elements) by 3 (the number of linguistic variables) and using the ceiling function to obtain the result of 3. The floor could have been used but, as will be seen, that would have caused difficulties in dividing the base scale equally among the linguistic variables. Figure 4 illustrates the example fuzzy set as it appears at this point.

Once the sizes and divisions of the fuzzy sets are determined (as in the steps above) the *definitions* of the primary linguistic variables (e.g., *small, medium*, and *big*) must be established. That is, the membership values for each base scale element must be determined for each primary linguistic variable. The method used for this depends on the shape of the membership functions being used. Given the example sets in Figure 4, the membership values for each of the linguistic variables, *small, medium*, and *big*, can be

determined from Equation 2.4. After this determination, each linguistic variable will be described by a fuzzy set. The set for the linguistic variable *small* from the example set might look like this.

$$small = \{1/1, 0.5/2, 0/3, 0/4, 0/5\}. \tag{2.6}$$

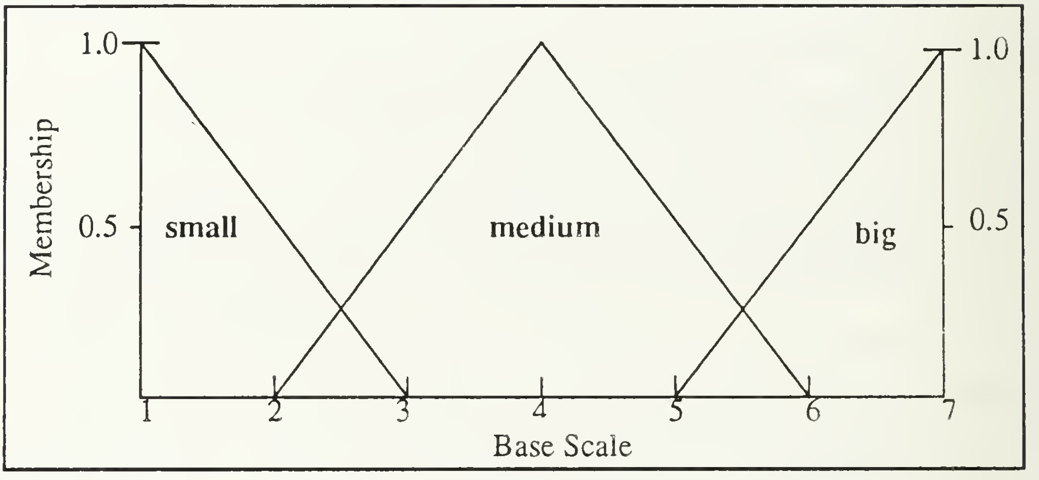

Figure 4: Example Fuzzy Sets

The last step required for creation of a fuzzy model from a set of linguistic variables or crisp numeric variables (variables without membership values) is to expand the set of linguistic variables using modifiers on the primary variables. These additional linguistic variables are produced by shifting or changing the degrees of membership of the primary variables. These expanded variables are called *hedges*. Hedges for the example set of linguistic variables described above might include *very low*, *pretty high*, or *slightly lower than medium*. These additions to the available linguistic variable set allow the user to describe ambiguous or vague relationships more accurately. As with the primary variables, the hedges actually used are up to the designer and/or user. In the sample set that has been used so far, hedges of *moderately small* and *moderately big* might reasonably be chosen. The positioning of the hedge variables is done the same as for the primary variables, as is the determination of the membership values of the base scale elements for each. The resulting model of the example fuzzy sets might look like Figure 5.

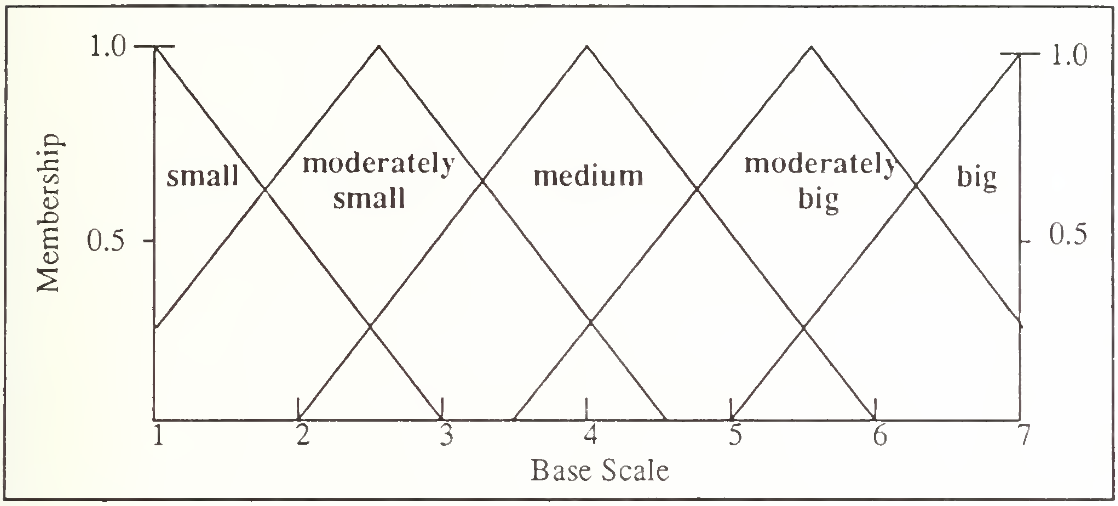

Figure 5: Fuzzy Model including Hedge Variables

With the inclusion of these two hedges (*moderately small* and *moderately big*) and their fuzzy sets, the model is complete. It should be noted that the fuzzy sets for the two hedge variables do not have a peak membership value of 1.0. This type of fuzzy set is said to be sub-normal. This does not affect the fuzzy operations described below when they are applied to these sub-normal sets. At this point, the fuzzy sets for all the linguistic variables of the example fuzzy model look like the following sets.

$$
\begin{aligned}
&\textit{small} = \{1/1, 0.5/2, 0/3, 0/4, 0/5, 0/6, 0/7\} \\
&\textit{moderately small} = \{0.25/1, 0.75/2, 0.75/3, 0.25/4, 0/5, 0/6, 0/7\} \\
&\textit{medium} = \{0/1, 0/2, 0.5/3, 1/4, 0.5/5, 0/6, 0/7\} \qquad (2.7) \\
&\textit{moderately big} = \{0/1, 0/2, 0/3, 0.25/4, 0.75/5, 0.75/6, 0.25/7\} \\
&\textit{big} = \{0/1, 0/2, 0/3, 0/4, 0/5, 0.5/6, 1/7\}.
\end{aligned}
$$

4. Fuzzy Set Operations

a. Fuzzification

Once the model for the fuzzy sets has been established, the fuzzification of inputs can be accomplished.The term *fuzzification* is used here to denote the conversion into fuzzy sets of linguistic variables (variables with words or phrases for meanings, e.g.,

very short or *pretty hot)* or crisp values (numeric variables). In the case where the input is a linguistic variable, the input is assigned the value of the appropriate fuzzy set. The entire fuzzy set of elements and membership values, over the complete base scale, is used even when some membership values are zero.

In the case the input is a crisp numeric variable (e.g., 3.3), the process is a bit more complicated. First the crisp value must be in the range of the base scale; otherwise it does not fit the model. If it does fit the model, it is possible that the crisp value will be encompassed by overlapping linguistic variable fuzzy sets. This is the case in the example shown in Figure 5. When this happens, all fuzzy sets that contain the crisp value within their non-zero membership bounds must be combined to form a single representative set. The combination is carried out using the fuzzy intersection operator, described below. This operation will return a single fuzzy set that accurately represents the crisp value and that can be used in further operations in the model. Several approaches can be taken to find the linguistic variable that most closely fits the fuzzy set that describes the input crisp value, as will be described later.

b. Intersection

In classical set theory, the intersection operator is used to find the subset of elements that are common to two or more sets. In fuzzy set theory, each element has a membership value that expresses the vagueness of the original linguistic variable. Each fuzzy set must include all elements of the base scale, not just those with non-zero membership values. For these reasons the simple classical intersection operator does not work for fuzzy sets. A fuzzy set intersection operation was proposed by L. A. Zadeh in 1965 [Ref. 8]. For each element of each fuzzy set being used, the minimum of the membership values for that element is determined. That minimum value then is used as the membership value for that element in the set representing the intersection. Notationally this is expressed as follows.

$$\forall x \in X \ : \ \mu_{A \cap B}(x) \ = \ min(\mu_A(x), \mu_B(x)). \tag{2.8}$$

The use of the minimum value is not the only method of accomplishing the intersection of several fuzzy sets but it is commonly used [Ref. 9]. Two of the fuzzy sets of the example model defined earlier can be used to demonstrate this operation.

$$\begin{aligned} &\textit{moderately small} = \{0.25/1, 0.75/2, 0.75/3, 0.25/4, 0/5, 0/6, 0/7\} \\ &\textit{medium} = \{0/1, 0/2, 0.5/3, 1/4, 0.5/5, 0/6, 0/7\} \\ &\textit{moderately small} \cap \textit{medium} \ = \ \{0/1, 0/2, 0.5/3, 0.25/4, 0/5, 0/6, 0/7\}. \end{aligned} \tag{2.9}$$

c. Union

Like the intersection operator, the union operator of classical set theory does not work for fuzzy sets. Zadeh proposed a fuzzy set union operation to achieve this method of combination. For each element, the maximum membership value of that element for all the fuzzy sets being joined is determined. That value is used as the membership value for that element in the set representing the union of the other sets. Notationally this is expressed as follows.

$$\forall x \in X \ : \ \mu_{A \cup B}(x) \ = \ max(\mu_A(x), \mu_B(x)). \tag{2.10}$$

As with the intersection operator, several other methods can be used to accomplish the union operation; however the maximum operation is commonly used [Ref. 9]. Using the two fuzzy sets defined previously, *moderately small* and *medium*, the notation for this union operation is:

$$\textit{moderately small} \cup \textit{medium} \ = \ \{0.25/1, 0.75/2, 0.75/3, 1/4, 0.5/5, 0/6, 0/7\}. \tag{2.11}$$

d. Complement

The complement operator for fuzzy sets takes the complement of the membership values associated with each element of the fuzzy set. This is done by subtracting the membership value of each element from 1.0 and using the result as the

membership value for the fuzzy set representing the complement of the original set. Unlike the intersection and union operators, the complement operator works on a single set rather than on a group of sets. The notational representation of this operator is:

$$\forall x \in X : \quad \neg\mu_A(x) = 1 - \mu_A(x) . \tag{2.12}$$

An example using the fuzzy set *medium* (as defined above) is as follows.

$$\neg medium = \{1/1, 0.5/2, 0/3, 0.5/4, 1/5\} \tag{2.13}$$

where $\neg$ is the symbolic representation of the complement.

e. Other Fuzzy Operators

Other operators for manipulating fuzzy sets include addition, division, multiplication, concentration, dilation, and extension. These operators are outside the scope of this thesis and are not described here.

f. Defuzzification

Defuzzification is the process by which a crisp output or a linguistic variable is obtained from a fuzzy set after other operations have been performed on the set. Several methods for accomplishing this defuzzification exist. Among these are the Center of Sums, Center of Largest Area, Best Fit, and First of Maxima methods [Ref. 9]. In the fuzzy model developed in this study, the Center of Sums defuzzification method is used.

The Center of Sums defuzzification method yields a crisp number output from a fuzzy set. For each base scale element, the membership value of that element is multiplied by the value of that element (e.g., 0.5 x 3.0). The sum of these products is then divided by the sum of the membership values of all the elements. The division and multiplication are standard arithmetic operations, not the fuzzy set operations. The computational simplicity of this method is a major reason it is widely used in fuzzy control

systems. Using the fuzzy set obtained by the intersection operation described above, the final division would be:

$$2.5/0.75 \tag{2.14}$$

where 2.5 is obtained from (0.5 x 3) + (0.25 x 4) (all others equaling 0), and 0.75 is obtained from 0.5 + 0.25.

The Center of Largest Area method is useful in situations where the crisp output must be determined from more than one fuzzy set. The area of each fuzzy subset is determined using standard integration and the central value of the fuzzy set with the largest area is returned as the output. This is computationally more expensive than the Center of Sums technique but it operates when a single fuzzy set can not be obtained or is not desired.

The Best Fit method returns a linguistic variable which corresponds to the linguistic fuzzy set closest to the final fuzzy set. This is done by obtaining the squares of the differences of the membership values of the resultant fuzzy set and the original fuzzy set, summing these differences, then taking the square root. This process is repeated for each linguistic variable, using the original fuzzy set for that variable. The linguistic variable with the minimum distance is then output.

The First of Maxima is another defuzzification method that can be used with multiple final fuzzy sets. It can also be used if the fuzzy set has been clipped. Clipping is done by taking the maximum membership value for a fuzzy set and extending it to the other side of the bell or triangle that forms the distribution for the fuzzy set. This eliminates any value above this maximum membership value and turns the distribution into a trapezoid or a clipped bell, depending on the original form. Figure 6 shows an example of a clipped set using the example fuzzy set *moderately small* described above.

The First of Maxima is simply the lowest value on the base scale where this maximum value occurs. In the case of multiple fuzzy sets, the maximum value of all the sets is determined and the lowest value on the base scale of this maximum of maximums is used as the output. For example, using the First of Maxima method and the fuzzy sets shown in Figure 6, the crisp number that would be output would be 2.0. This is the lowest

element value where the maximum membership value of all the fuzzy sets, 0.75, is encountered.

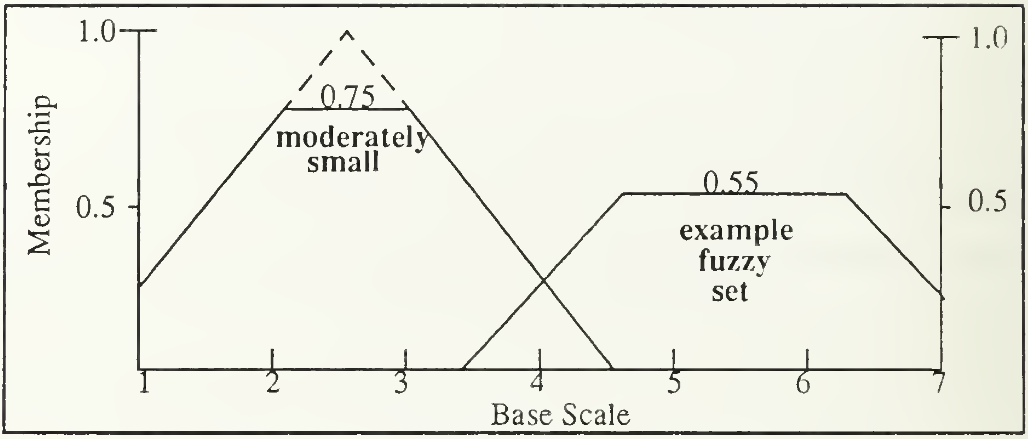

Figure 6: Example Clipped Fuzzy Sets

III. PROPOSED HUMAN FACTORS FOR TARGET ACQUISITION

A. MODELED HUMAN FACTORS

The human factors simulated in the proposed fuzzy logic model were chosen after a study of recent literature relating to human performance and the factors affecting it. That human performance is affected by various psychological and physiological factors can not be argued. What can be argued is the details of which factors are involved and how performance is or can be affected by each.

In this study human factors of interest are divided into attributes and subfactors. *Attributes*, as used here, are the major factors affecting the accomplishment of some task. In this model, the task is one of target search and acquisition by military ground units, either with or without the aid of mechanical or optical sensor systems. The *subfactors* are the various elements that contribute to the improvement or degradation of the attributes. Different attributes are affected by different subfactors, though some subfactors may affect more than one attribute.

Many of the attributes and subfactors used in this study have been the subjects of field and laboratory experiments. Many of these experiments have been conducted at the request of the United States government and its military services. Others have been conducted by commercial industries, and still others have been conducted by academic institutions. The purpose of all these studies has been to identify and measure the specific subfactors that affect attributes of human performance under various conditions. Some of the attributes and subfactors used in this model have not been studied individually but are believed to be of importance by the author, based on personal experience. The attributes and subfactors used in this study are discussed below.

1. Attributes Modeled

a. Attention Level

Attention level is defined here as the level of active concentration on the target acquisition task. It is the amount of conscious mental focus that is directed towards the search and acquisition process. It should seem obvious that a person's attention level affects the performance of most tasks. In the context of this study the attention level of an arbitrary observer is the amount of focus on the target area or sensor displays directly associated with the search effort.

Because of the obviousness of the effects of this attribute with respect to task performance, no research has been reported on its relationship to target acquisition. Instead many studies have been done which deal with the subfactors involved in degrading the attention level [Ref. 10:p. 257]. Studies of radar and sonar operators in particular are common, using scenarios similar to that of this study [Ref. 2].

Attention level is incorporated into the proposed model as a fairly high-level concept. This allows the model to be divided into two levels of detail. Users of the system can specify the levels of the subfactors related to attention, as these affect overall task performance.This is an easier setup task than if the subfactors were not grouped under a major concept.

b. Distraction Level

Distraction level is defined here as the level of other activities that the observer must deal with that detract from the time available for search and acquisition tasks. Distraction may have an effect on other attributes related to target acquisition performance, but also is considered a major factor in the overall acquisition process. For that reason it is presented here as an attribute.

As with attention, there have been few studies of whether distractions detract from task performance since it is fairly obvious that they do. The studies that have

been conducted have dealt with the areas that this model calls subfactors, described in detail later in this chapter.

c. *Workload*

For this study workload is defined as the complexity of the controls and displays necessary to operate the observation equipment and the difficulty and complexity of maintaining this equipment. Workload is included as an attribute in this study because of the increasing complexity of modern military equipment and, with this complexity, a tendency towards a lack of equipment robustness.

Much research has been conducted on the performance effects of various display and control complexities [Ref. 11:p. 187]. Some of this research has been initiated by commercial industries trying to improve worker performance through ergonomic engineering [Ref. 7]. Research also has been done by the military services to ensure that the increasingly complex weapons systems necessary for success on today's battlefields are usable under combat stress situations [Ref. 11:p. 187].

d. *Physical Stress and Fatigue*

The definition of physical stress and fatigue used here is the physical discomfort associated with use of the observational equipment or the observational position, and the physical health and fatigue of the observer. This attribute is included because of the nature of search and acquisition task. Usually such a task requires an extended time of observation with little movement of the observer. This can lead to severely degraded performance if the observer is fatigued or sick. An uncomfortable position, either due to environmental factors or to the size and physical layout of the observation post, can add to an already fatigued soldier's stress, thereby lowering further his search and acquisition performance.

Research on the effects of fatigue on task performance has been carried out for a wide variety of tasks and environments. Most of this research has been directed towards the military aspects of fatigue [Ref. 12]. Past military operations provide evidence

that combat is extremely fatiguing, even to the point of causing the physical collapse of soldiers' during combat. The requirement for soldiers mobility, regardless of transportation availability, also requires knowing how far the soldiers can travel and still be capable of fighting effectively.

e. *Mental Stress*

Mental stress is defined here as the stress imposed on an observer due to the mental requirements of his total task load. This task load is not limited to the observational tasks. It may include all tasks for which he holds responsibility, both externally defined, by job description, and internally assumed, by personal actions and feelings [Ref. 13]. The task load may include tasks which are not a part of the current operation or situation. This attribute might also be thought of as mental distraction due to the pressure of the observer's self-imposed mental task load on his current state of mind.

Again, much research has been done on the effects of mental stress on combat performance, particularly as it affects decision making and command [Ref. 12]. For the purposes of this study, the distraction from the search and acquisition tasks resulting from this mental stress are the main concern.

f. *Vigilance Level*

Vigilance level is defined for this study as the level of alertness of the observer. This alertness need not be consciously directed toward anything in particular to be active. Vigilance is not the same as attention (at least not for this study) as it is not necessary to focus on anything to be vigilant. This concept includes awareness of the surrounding environment, the sense of rightness, and the readiness to react to the situation based on this awareness.

Considerable research has been reported on the concept of vigilance [Ref. 2]. However, much research supposedly concerning vigilance really deals with the concept of attention, as defined for this study. As used here, vigilance is the readiness and awareness of an observer which allows him to sense when a situation may present a danger of enemy

engagement, even though he may have no hard evidence to explain his feeling of imminent danger.

2. Attribute Subfactors

a. Attention Level Subfactors

Four subfactors are proposed to have an effect on the attribute of attention level. The degree to which each subfactor affects this attribute is not specified because the effects are different for each individual. In the proposed fuzzy logic model the degree of a subfactor's effect is specified by the simulation user This is done as an input to the fuzzy logic calculations for each unit, prior to the start of the simulation run. The user's input and its use are further described in Chapter V.

(1) Current Operational Workload. This subfactor is defined here as the amount or number of concurrent operational tasks the observer must perform. For example, if the observer is also the driver of a stationary vehicle then the operational workload would be low, provided he was not detailed to other tasks. However if the vehicle were moving then his workload would be higher, leaving less capability for observation. There is ample evidence from both civilian and military experiences that the higher the task loading the less time can be devoted to any single task. This problem has been well studied, particularly in the areas of system design [Ref. 11:p. 187]. As used in this study, the higher the current operational workload, the lower the level of the observer's performance on the search and acquisition task.

(2) Level of Enemy Threat. This subfactor is defined here as the perceived probability of encountering enemy forces at the current time. If the observer were in a friendly rear area base camp or safe zone, the perceived probability of enemy encounters might be low, and thus the observer's attention to search and acquisition tasks might be low. However, in contested areas or where the threat of enemy encounter is higher, the observer may be more attentive to these tasks. This increase in attention to the

observational task comes at the expense of attention to other tasks that are not perceived to be critical to meeting the perceived threat. The field of attention narrows to exclude these less critical tasks [Ref. 11:p. 186] and the observer's performance on the search and acquisition task increases. For the purposes of this study, a lower enemy threat level implies a lower level of performance by the observer because of a lower perceived importance of the search and acquisition task.

(3) Interactions with Other Members of the Immediate Unit. It is assumed here that interactions with other personnel enhance the observer's ability to perform the required search and acquisition tasks. A crew can divide the search area into sectors that may be split among them, take care of minor interruptions such as radio traffic that might otherwise require the observer's attention, and take other actions that will allow the observer to devote his mental capacities to the task at hand. This is known as *crew coordination* in the military, and has the effect of lowering the amount of non-productive duplication of effort and cross-checking that would otherwise add to the observer's tasking. Crew coordination is taught by all military services as the primary method of increasing the efficiency and capability of any crew-served system. Research on the effects of continuous or sustained operations has shown this division of labor to increase individual and unit performance [Ref 10:p. 271]. As applied to this study, the higher the interaction level of the crew, the higher the performance of the observer.

(4) Personal Stress. As used in this study, personal stress consists of those personal concerns that may distract the observer from his current task. Concerns might include such things as career decision points, promotion, job transfer, and financial or family problems. Such stressors replace or dilute thoughts of the current search and acquisition process. Feelings about the rightness or purpose of the observer's current operations, either on a local scale or on a broader, overall scale, may also be included in this subfactor. Researchers have found that the stress of conflicting moral values or anxiety about a soldier's family or other non-military obligations and responsibilities can lead

eventually to a state of mental and/or physical collapse [Ref. 12]. Because of this possibility, the higher the personal stress, the lower the performance of the observer.

b. Distraction Subfactors

Seven subfactors are proposed as having an effect on the distraction of an observer. As defined earlier, distraction is the amount of other tasks and stimuli that are present and that interfere with an observer's ability to perform the search and acquisition tasking.

(1) Current Operational Intensity. Operational intensity refers to the complexity and amount of combat in the observer's general area. This includes combat that the observer is not directly involved in but that could reasonably be expected to shift to include him. The greater the probability of the observer receiving fire or the more time required to defend the observer's position or those in close proximity, the less time or capacity will be available for search and detection processes [Ref. 12:p. 254]. In this definition, the detection of targets that are not already engaged by the observer is the goal.

(2) Level of Enemy Threat. As defined earlier, this subfactor is the perceived probability of encountering enemy forces at the current time. If the observer were in a friendly rear area base camp or safe zone, the perceived probability of enemy encounters might be low. Hence the observer would not be distracted by other tasks such as preparing for an engagement with an enemy unit. A decrease in observer distraction is likely, due to the need to meet the perceived threat in a good state of preparation. For the purposes of this study, a higher perceived enemy threat implies a lower level of performance by the observer because of distractions from the search and acquisition task [Ref. 11:p. 186].

(3) Probability of Observation System Failure. An observer's confidence in the functionality of the observation equipment and the expected frequency of failure of all or part of the equipment affect his distraction level. The more probable that there will

be a failure in the equipment, the more time the observer will spend on functional checks. These equipment checks will be more thorough and the results scrutinized more closely, thus adding to the time required for completion. The time spent on these checks is not available for search and acquisition task, and a reduction in the performance of this task will ensue.

(4) Negative Interaction with Other Members of Immediate Unit. Interactions with other personnel can detract from the observer's ability to perform the required search and acquisition tasks. Unlike crew coordination interactions described for the attention level attribute, these interactions take away from the time an observer has for accomplishing the search and acquisition tasks. Thus this type of interaction is the antithesis of the crew coordination described earlier. As applied to this study, the higher the negative interaction level of the crew, the lower the performance of the observer.

(5) Level of Combat Experience. Combat experience is defined here as the amount of time spent in combat operations. This includes the time actually engaged with enemy forces plus the time spent in situations that had a high probability of such engagement, even if it did not materialize. Much research has been done on the simulation of combat in training with the goal of improving the performance of soldiers in their first real combat engagement [Ref. 12:pp. 79-88]. While much benefit has been derived from these studies, most researchers feel that there is no substitution for real combat. The performance of combat-experienced soldiers is almost always better than that of inexperienced soldiers, assuming no psychological problems are present. It is this level of increased performance that is modeled by this subfactor. For the purposes of this study, the higher the level of combat experience of an observer (measured in total combat time), the lower the distraction level of that observer.

(6) Level of Combat Training. Combat training is considered to be the amount and sophistication of training in combat operations directly related to the observer's role in the unit. Training is where the essentials of combat are learned. With

more and higher-level training, the observer is more likely to survive his first combat engagement. Better trained observers are more proficient in using and maintaining the equipment required for task completion (in this case search and target acquisition), particularly when under the stress of impending combat [Ref. 11]. Training in situations and over terrain likely to be encountered also provides the observer with knowledge about environmental affects on the operation of his equipment. The effects of shadows, heat, fog, and terrain contrast on his ability to detect enemy units can be learned during realistic training exercises. Much research has been done on this subject and, while it cannot replace experience, realistic training can greatly enhance the observer's performance [Ref. 12:pp. 79-88]. Much of this improved performance is attributed to better judgements about what is important and what is relatively trivial Such judgements lower the effect of distracting stimuli because they are tuned out by the observer. In this study, the higher the training level of an observer, the lower the distraction level, and the higher the observer's performance.

(7) Target Area Extraneous Distractions. For the purpose of this study, this subfactor includes both the movements of friendly units near the observer's position and the movement or activities of civilians near his position. Any activity that might detract from the observer's interest in the search and acquisition task (such as workers in a field, sunbathers, etc.) is considered to increase the level of the observer's distraction. Thus, the higher the level of extraneous activity the lower the observer's performance.

c. Workload Subfactors

Four subfactors are proposed by this study as having an effect on the workload of an observer attempting to search for and acquire targets on a battlefield. As defined earlier, the workload is considered to be the complexity of the controls and displays necessary to operate the observation equipment and the difficulty and complexity of maintaining it.

(1) Number and Complexity of Search and Weapons Systems. The number of different search and/or weapons systems employed at one time by the observer increases the workload. A larger number of control operations must be carried out and, unless the systems are all of the same type, multiple control sequences must be remembered. The complexity of the systems can also increase the workload if the controls and displays required for operation are not well designed. As noted earlier, a great amount of commercial research has been done on the optimum design of displays and controls [Ref. 3]. Most of these efforts have been directed at reducing the operator workload while using complex equipment. For the purposes of this study, a larger number of search and weapons systems or greater complexity of these systems increases an observer's workload and decreases his performance.

(2) Level of Training Using Search and Weapons Systems. Level of training is defined here as familiarity with and knowledge of the applicable search and weapons systems, their controls, and their operation. The ease with which an observer uses the observational equipment lowers the total workload involved in search and detection operations due to a decreased need to search for the correct control or to determine the correct method of display. Training in the system's design, functions, and capabilities is necessary for ease of use. Training in system use is separate from operational training where the real systems are used, and may include classroom and individual study of the systems. For this study, the more familiar an observer is with the applicable systems, the higher his performance level during the use of the systems.

(3) Level of Experience Using Search and Weapons Systems. This is defined here as the amount of actual hands-on training and the amount of use of the real systems in both structured and realistic scenarios. It has long been a practice of the military services to train soldiers with full capability and up-to-date equipment in realistic conditions as a method of increasing the soldiers' performance under combat conditions [Ref. 12:pp. 79-88]. This is done in an attempt to make the operation of essential equipment

as automatic as possible in the hope that automatic responses will continue even during the stress of combat [Ref. 11:p. 188]. Practice with non-operational systems is fine for functional training but, until the real equipment is used, the operator will not have full confidence in the system. More and higher-level training with the actual systems increases the operator's confidence in the equipment, along with the ease with which he uses it. For the purposes of this study, a higher level of experience in using the search systems decreases an observer's workload and increases his performance.

(4) Probability of Observation System Failure. As defined earlier, this subfactor reflects the observer's perceived confidence in the functionality of his observation equipment along with the expected frequency of failure of all or part of the equipment. As noted for the distraction attribute, the more probable that the equipment will fail (in the observer's opinion), the more time will be spent on functional checks. These checks will be more thorough, adding to the observer's workload by requiring the observer to recall possibly obscure test sequences and possible failure modes. For this study, the higher the perceived probability of a system failure, the higher the workload and the lower the performance of an observer using the system.

d. Physical Stress and Fatigue Subfactors

Nine subfactors are considered to affect the physical stress and fatigue of an observer on a battlefield. Physical stress and fatigue are defined as the physical discomfort associated with use of the observational equipment or the observational position, and the physical health and fatigue of the observer.

(1) Length of Operational Involvement. This subfactor is used here to mean the total length of time since the start of the mission or operation. The physical stress related to combat operations increases as the length of the mission or operation increases; stress and fatigue accumulate with time. Studies of World War II operations have focused on the length of combat operations that soldiers can endure [Ref. 10]. These studies conclude that the longer the operation, the more fatigued soldiers become. For this study,

the longer the mission or operation has been going, the higher the fatigue level of an observer and the lower his performance level while engaged in the search and acquisition task.

(2) Cumulative Time Engaged with Enemy. This subfactor reflects the total amount of time engaged in combat since the mission started. Any combat operation is physically taxing, but the effects of actual engagements on the fatigue of soldiers is immense [Ref. 12:pp. 231-234]. The stress and fatigue of combat (including both actual physical effort and physical tension that is the result of the enemies' combat actions) accumulates if the soldier is not given time for recovery, greatly affecting the performance of all tasks [Ref. 13]. For this study, a higher accumulation of time engaged with enemy forces corresponds to a lower level of performance for an observer.

(3) Physical Difficulty of Operating Search and Weapons Systems. This subfactor is defined here as the actual physical effort required to operate the search and weapons systems employed. Difficulty in using a system leads to increased physical exertion during the time the systems are used. If these periods of usage are long or numerous, the fatigue level of the user increases. In this study, the more physically difficult it is to use the systems, the higher the fatigue level of the user and the lower the performance level of that user.

(4) Level of Observer's General Health. The effects of illness or injury on fatigue are well known. Anyone who has had even a cold has experienced the increased fatigue associated with the illness. An injury is even more debilitating because of the energy requirements of the body during the healing process. Not only do illness and injury cause an increase in fatigue, they also increase the fatigue from other sources such as physical and mental activity. An injury may also interfere with the proper operation of the search and weapons systems in use and may cause further physical stress or fatigue from operating this equipment in a manner for which it was not designed. The amount of time required for the performance of the search and acquisition task may increase due to an

illness or injury. For the purposes of this study, the higher the level of health of an observer, the higher the level of performance of that observer.

(5) Environment. This subfactor is defined here as the effects of environmental conditions on the fatigue and physical stress of an observer. Conditions such as low or high temperatures, high humidity, rainfall, and other environmental factors can affect the level of fatigue of a soldier [Ref. 12:pp. 242-243]. The lack of shelter or an enclosed position may affect not only the observer's physical fatigue and stress, but they may also lead to illness or equipment malfunction. For the purpose of this study, a higher rating for this subfactor implies better environmental conditions, a lower rating implies adverse environmental conditions. The higher the rating for this subfactor, the better the performance of an observer on a search and acquisition task.

(6) Level of Protective Gear Required. The level of protective clothing required for the current combat conditions will affect stress and fatigue levels. Conditions such as extreme heat or cold (which require special protective clothing) or chemical, biological, or radiological conditions or the threat of thereof (which require a high Mission-Oriented Protective Posture (MOPP) level) may severely restrict the physical ability of the operator to employ the required system to its full capability and thus greatly increase the rate of fatigue buildup for the wearer [Ref. 10:p. 270]. In the worst case, protective clothing may totally prevent the use of the system, though this would be an uncommon situation. For this study, a high level of required protective gear will increase the fatigue and stress of the wearer and lower his search and acquisition performance.

(7) Amount of Sleep or Rest Prior to Mission or Operation. As defined here, this is the amount of rest and sleep the observer was able to obtain in the 36 hours immediately preceding the mission or operation. It is not possible to store or accumulate sleep for use at a later time, but starting an operation fully rested will delay the increase in fatigue due to sleep loss [Ref. 10:p. 267]. A time frame of 36 hours prior to the start of the mission or operation is used because it was felt to be the time frame which most affects the

upcoming operation. As used in this study, the higher the level of rest or sleep in the 36 hours prior to the mission or operation, the lower the fatigue level of the observer.

(8) Amount of Sleep or Rest During Mission or Operation. The ability of a soldier to rest and sleep during the operation depends on the amount of travel, the engagements that take place, and the type of mission. Adequate rest is essential to the continued performance of any tasks, particularly complex ones. Many studies have shown the performance degradations that occur due to inadequate quantities of sleep for extended periods of time. In one of these studies [Ref. 10:p. 268], subjects deprived of sleep for approximately 72 hours were considered militarily ineffective, as judged by the performance of general military tasks such as marching, digging, weapon handling, and patrolling. Another study [Ref. 14] found performance degradations of approximately 50% after 48 hours of sleep deprivation, and the same decreased level of performance after 5 to 7 days of partial sleep deprivation (sleep limited to 4 to 5 hours per night). While most of the studies conclude that mental performance declines faster than physical performance, physical performance is affected nonetheless. This leads to an increased amount of time and effort required to accomplish any task, along with increased physical fatigue and stress. For the purpose of this study, a higher level of sleep during the mission corresponds to a higher level of performance by an observer.

(9) Availability of Food and Water. The access to and consumption of adequate food and water are necessary for continued human life (in the extreme) and to the continued exertion of physical and mental energy. The lack of either (though particularly water) will rapidly lead to conditions of physical exhaustion, dehydration, and eventually death if allowed to progress far enough. These conditions are not conducive to high performance levels. In studies of combat endurance, the lack of food and water have been found to affect the fatigue level of soldiers and to increase the perceived fatigue of the individual [Ref. 12:p. 245]. For this study, a lack or low level of available food and water

will increase the physical fatigue of an observer. This will, in turn, lower his performance on a search and acquisition task.

e. Mental Stress Subfactors

For this study, seven subfactors are proposed as affecting the mental stress of a random observer on a modern battlefield. Mental stress, as defined previously, is the stress imposed on an observer due to the mental requirements of his total task load.

(1) Length of Operational Involvement. This quantity, as used here, is the total length of time since the start of the mission or operation. Mental stress related to combat operations increases as the length of the mission or operation increases and as the stress of continuous danger and anxiety about possible enemy actions accumulates. Studies done during and after World War II have shown that the stress of combat operations increases as the length of the operation increases. This was judged by the increased number and type of psychiatric casualties ("combat fatigue" or "combat exhaustion") which were processed during lengthy campaigns such as the breakout from the Normandy beachhead or the Italian campaigns of 1944 [Ref. 12:pp. 272-280]. From these studies it is concluded that the longer the operation, the more mental stress a soldier accumulates and the lower the performance level of these stressed individuals. For the current study, the longer the mission or operation has been running, the higher the mental stress level of an observer and the lower his performance level during the search and acquisition task.

(2) Level of Training Using Search and Weapons Systems. Level of training is defined here as the familiarity and knowledge of the applicable search and weapons systems and their controls and operation. This subfactor deals with the confidence of an observer in the capabilities of the search and weapons systems being used to provide the necessary data for the accomplishment of his task. Such confidence is an important factor in the success of any endeavor. Confidence is even more important in a military context for reducing the susceptibility of soldiers to mental stress. Thorough training in the operation of his equipment (as one of the many military skills used by a soldier) is crucial

to this confidence [Ref. 12:p. 324]. For this study, the more thoroughly trained an observer is with the applicable systems, the higher his performance level during the use of the systems and the lower the mental stress level of this observer.

(3) Level of Experience Using Search and Weapons Systems. This subfactor is defined here as the observer's actual hands-on training and his use of the real systems in both structured and realistic scenarios. More training with the actual systems increases the operator's confidence in his abilities to use the observation equipment and in the equipment itself. This increased confidence lowers the mental stress associated with the use of this equipment. For the purposes of this study, a higher level of experience in using the search systems decreases an observer's mental stress and increases his performance.

(4) Observer's Command Level. Command level is defined for this study as the organizational leadership level or command authority of the observer. The higher a soldier's leadership level in a unit, the greater the assumed responsibility that is held by that soldier, in most cases. As found in several studies of combat leadership [Ref. 12:pp. 236-238], this responsibility imposes more stress on the leaders due to the consequences of their actions and the effects of their decisions on the others members of the unit [Ref. 13:pp. 80-81]. This additional stress can interfere with the efficient performance of the leader, particularly in a high stress situation such as combat. As used in this study, a higher level of command implies a higher level of mental stress and lower performance as an observer.

(5) Time Available for Search. For this study, this subfactor is defined as the perceived time available for the search task. A shorter perceived time (or a perceived urgency) can increase the mental stress of an observer as he attempts to force detection prior to an actual target being observable. This perceived time may be longer than actually available or it may be shorter. In the case of longer perceived time, the mental stress may not be increased as much but that may leave the observer open for an unexpected engagement. Shorter-than-actual perceived time may lead to considerably increased mental

stress as the observer attempts to detect an expected but not yet physically detectable target, knowing that others are relying on his skill and judgement, and knowing that failure on his part may cause others harm. A higher urgency or shorter perceived search time will increase an observer's mental stress and will decrease the observer's performance on the search and acquisition task.

(6) Probability of Observation System Failure. An observer's confidence in the functionality of the observation equipment or the expected frequency of failure of all or part of the equipment will affect his mental stress level. Because the consequences of failing to detect an enemy unit may be grave for the observer or other members of his unit, a lack of confidence in the equipment needed to detect the enemy will increase the mental stress of the observer and detract from his search and acquisition performance. For the purposes of this study, a higher perceived probability of failure or a lower confidence level increases the mental stress and lowers task performance.

(7) Personal Stress. The level of this subfactor reflects personal concerns (other than those about the immediate situation) that may increase an observer's mental stress. As noted earlier, career decision points, promotion, job transfer, and financial or family problems can cause concern and anxiety on the part of the observer. Mental stress may be increased by concerns about the moral or political nature of the current operation or of the overall combat situation. The stress of conflicting moral values, family anxiety, etc., can result in mental exhaustion. [Ref. 12]. Thus, a higher level of personal stress means a higher mental stress level and lowered observational performance.

f. Vigilance Level Subfactors

Four subfactors that affect the vigilance level of an observer on a typical battlefield are defined below. Vigilance level, as defined earlier, is the level of alertness of the observer and is expected to affect target acquisition performance. This alertness need not be consciously directed toward anything in particular to be active. Vigilance differs from attention in that it is not necessary to focus on anything to be vigilant.

(1) Length of Operational Involvement. This subfactor is defined here as the total length of time since the start of the mission or operation. The stress related to combat operations increases as the length of the mission or operation increases, and this stress wears down the mental sharpness of soldiers after an extended time. Stimuli that would alert the soldier at the beginning of the operation may not do so later in the mission. This may is particularly true when the soldier is physically fatigued by exertion and sleep loss. Studies of the performance degradation of soldiers due to fatigue have found that all mental tasks are highly susceptible to fatigue effects, and that vigilance tasks are particularly affected [Ref. 10:p. 258]. Based on this research, the current study equates length of an ongoing mission to the increased fatigue level of an observer and to reduced vigilance.

(2) Level of Distraction. The attribute distraction, as described earlier, is included as a subfactor of the attribute vigilance level. The reason for this is found in the definition of vigilance as used here: the awareness and readiness to react to a possibly dangerous situation, even without evidence that the situation is, in fact, a danger. A high level of distraction presents the observer with many possibly dangerous situations and reduces the amount of time and mental capacity the observer can devote to any one situation as he tries to evaluate it for real danger. Also, if the observer feels the situation may present a danger, he may not be able to maintain the vigilance level required to determine which of the various situational participants is the cause of this unease or sense of danger.

(3) Amount of Sleep or Rest Prior to Mission or Operation. For this study, the amount of rest and sleep the observer was able to obtain in the 36 hours immediately preceding the mission or operation is the factor of interest. As previously noted, sleep loss affects the mental functioning of a person more, and earlier, than it does his physical functioning. As vigilance is mainly a mental awareness (though coupled with a physical readiness to act) the amount of sleep affects this attribute. As used in this study, the higher

the level of rest or sleep in the 36 hours prior to the mission or operation, the lower the fatigue level of the observer and, hence, the higher the vigilance level of this same observer.

(4) Amount of Sleep or Rest During Mission or Operation. The ability of a soldier to rest and sleep during the operation will affect his continuing vigilance level. Numerous studies have shown the performance degradations that occur due to inadequate quantities of sleep for extended periods of time. Most of these studies conclude that mental performance declines faster than physical performance [Ref. 10:p. 258]. As vigilance is a largely mental attribute, this degradation of mental processes must also affect the vigilance level to some degree. For the purpose of this study, a higher level of sleep during the mission corresponds to a higher vigilance level for an observer.

B. USE OF MODELED HUMAN FACTORS

The six human factors attributes and their related subfactors, defined above, are proposed for use in the calculation of an overall target acquisition performance rating for individual observer units. This performance rating can then be used as a modifier for the probability of target detection now used by the JANUS (A) simulation system.

In the new model, the subfactors are weighted individually based on their relative importance to the attribute of which they are members. Each subfactor is assigned a value that represents the level of that subfactor in the unit or observer under consideration. The subfactor values are used together to determine the overall level of each attribute in the unit or observer. Together the attributes describe the overall state of capability or performance of a unit or observer from a human factors perspective. The unit or observer's capability state can be used as a modifier for the probability of detection as currently calculated for the JANUS (A) simulation system. The resulting modified output should more closely represent the total process of target acquisition, adding recognition and identification capabilities to the simple detection task now considered during combat simulations. Both realism and usefulness should be improved.

The implementation of the human factors model proposed for incorporation in the JANUS (A) system is described in Chapter V. As the implementation is only a prototype, testing the effects of this incorporation is left for further research and study. However, adding, subtracting, and changing the human factors used in the prototype is a possible and expected modification that can be easily accomplished as more data are collected and testing begins.

IV. DATA COLLECTION AND ANALYSIS

A. COLLECTION OF SUBJECT MATTER EXPERT OPINIONS

1. Survey Background

Human factors simulation data related to the target acquisition attributes and subfactors of interest are essentially unavailable. Thus a survey was undertaken to determine the relative importance of these attributes and subfactors, as judged by subject matter experts. The experts who participated in the survey were U. S. soldiers taking part in system evaluation exercises at Ft. Hunter-Liggett, California, during February 1994. The survey was conducted via a detailed, structured questionnaire, included as Appendix A.

2. Subject Matter Experts

The JANUS (A) system is primarily a ground unit battlefield simulator. The proposed model affects only the target acquisition portion of this ground combat system. Thus the appropriate subject matter experts are those with experience in ground combat operations or exercises and who also have experience in target acquisition tasks during these operations or exercises. The personnel deemed most likely to have this experience were U.S. Army personnel, with either infantry or armor training. Actual combat experience was not deemed essential, but such experience would be an additional bonus, and those with recent operational experience were preferred over those long absent from these duties.

This choice of personnel to serve as subject matter experts led to the selection of a group of soldiers who were participating in a weapons test program in at Ft. Hunter-Liggett military reservation. The weapons testing included the acquisition of ground targets by the test personnel using the target acquisition systems of M1 tanks. The targets were live vehicles and the test was completed in both day and night environments. A total of eight soldiers participated in the tests and were administer the survey in Appendix A.

3. Questionnaire Development

A structured questionnaire was developed in accordance with the guidelines from the *Army Questionnaire Construction Manual* [Ref. 15]. The information desired was the relative importance of each subfactor for its related attribute and the relative importance of each attribute for the task of searching for and acquiring ground targets. The questionnaire also included a rating scale for the linguistic variables used for this study, five variables ranging from Very High to Very Low. Participants were asked which number, on a scale of 0-100, best describes each linguistic variable. Information was collected about each participant's military job experience, rank, and combat experience.

The questionnaire included detailed definitions for the attributes and brief examples for the subfactors. Since the relative importance of the attributes and factors depends to some extent on the type of combat operation, a brief scenario was included as an example ground combat mission, which is presented below.

- The observer is in the field as part of a ground combat unit, involved in a quick response action in a Third World country. The combined action also includes military units from other nations. The action is a protracted one, expected to last for weeks or months.
- Locations of targets in the combat area are not known, so active search is critical.
- The possible targets may include enemy tanks, APCs, or other vehicles. Rules of engagement require that a target be positively identified prior to engagement.
- The observer has available an advanced portable weapon such as the Javelin, but is relying primarily on direct vision to locate potential targets. The weapon's sensor system may be used for identification, if needed.

4. Survey Administration

The survey was administered twice to the same group of eight soldiers, in order to determine test-retest reliability. The small number of participants precludes assuming that the precise relationships among attributes and subfactors have been established by this study. However, the number is considered adequate to indicate trends and rank ordering, and to serve as a baseline for any data that may be collected at a later time.

The first survey was administered by a civilian engineer who was involved in the Ft. Hunter-Liggett system evaluation exercises. Only seven of the eight soldiers who were to participate in the exercise completed the questionnaire. The survey was administered as a group; however each soldier completed a separate, individual questionnaire. This was done within a few days prior to the start of the system evaluation exercises.

The second survey was readministered several weeks later by the author after the exercise had been completed. The questionnaire was administered to the eight soldiers as a group in a closed classroom with the individuals separated from one another by approximately 10 feet. After a brief description of the purpose of the questionnaire and a brief overview of the scenario that was being considered, the participants again completed individual questionnaires (see Appendix A). The total time for all participants to complete the questionnaire was 20 minutes.

5. Participant Information

The subject matter experts surveyed for this study were all currently employed as crew members for the U.S. Army's M1 tank. They were all Army enlisted personnel who were past their first enlistment and could therefore be classified as career soldiers. Rank, length of service in months, length of time in months in their current specialty as M1 tank crew members, and combat experience for each participant are shown in Table 1.

As shown in Table 1, the average length of time in the current specialty for the survey participants was 95 months; that is 7 years and 11 months. The average time in service was 10 years, and 50 percent of those surveyed had combat experience. Due to the nature of search and acquisition tasks for the area of specialty of these participants the data obtained was considered relevant to the current study. The ranks of the participants ranged from E-4, specialist or corporal, through E-5, sergeant, and E-6, staff sergeant, to E-7, sergeant first class.

Table 1: PARTICIPANT PERSONAL DATA

Participant Number	1	2	3	4	5	6	7	8	Avg.
Rank	E-5	E-4	E-6	E-7	E-5	E-5	E-7	E-6	N/A
Length of Service (months)	60	28	120	168	32	144	228	180	120
Length in Specialty (months)	60	28	102	156	32	108	120	156	95
Combat Experience	NO	NO	YES	YES	NO	YES	NO	YES	N/A

B. RESULTS OF FIRST SURVEY

1. Survey Results for Subfactor Importance

Survey results obtained from the first administration of the questionnaire are reported here for individual subfactors for each of the six target acquisition attributes. Table 2 shows the results for the first survey question, which asked about the extent to which the four subfactors of the attribute Attention Level affect that attribute. The subfactor *level of enemy threat* was considered by almost all of the participants to be the most influential subfactor for this attribute. *Positive unit interactions* was considered the second most important subfactor, followed by *operational workload* and then *personal stress*.

Table 2: RELATIVE IMPORTANCE OF ATTENTION LEVEL SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Operational Workload (%)	-	15	22	24	11	25	29	24	**21**	11-29
Enemy Threat Level (%)	-	45	39	34	50	36	25	30	**37**	25-50
Positive Unit Interactions (%)	-	25	26	21	22	32	38	24	**27**	21-38
Personal Stress (%)	-	15	23	21	17	7	8	22	**15**	8-22

Survey results for the seven subfactors of the attribute Distraction (Question 2) are shown in Table 3. With a larger number of subfactors, the individual percentages are smaller, but the relationships among the subfactors can be clearly seen. The subfactors *extraneous distractions* and *combat training level* were deemed most important but not by a large margin. *Operational intensity* and *negative unit interactions* were also rated fairly highly by most of the participants.

Table 3: RELATIVE IMPORTANCE OF DISTRACTION SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Operational Intensity (%)	-	15	5	13	20	22	16	14	**15**	5-22
Enemy Threat Level (%)	-	4	20	19	15	10	6	19	**13**	4-20
System Failure Probability (%)	-	27	13	15	5	6	6	4	**11**	4-27
Negative Unit Interactions (%)	-	23	11	10	15	25	4	14	**15**	4-25
Combat Experience Level (%)	-	4	20	13	10	6	31	14	**14**	4-31
Combat Training Level (%)	-	12	20	15	10	6	31	16	**16**	6-31
Extraneous Distractions (%)	-	15	11	15	25	25	6	19	**17**	6-25

Table 4 shows the ratings for the four subfactors of the attribute Workload, (Question 3). *Systems training level* and *systems experience level* both received higher than average ratings from the survey participants.

Table 4: RELATIVE IMPORTANCE OF WORKLOAD SUBFACTORS

Participant number	1	2	3	4	5	6	7	8	Avg	Range
Number and Complexity of Systems (%)	-	53	19	19	23	4	19	14	**22**	4-53
Systems Training Level (%)	-	13	35	27	38	43	37	38	**33**	13-43
Systems Experience Level (%)	-	7	27	27	31	43	37	38	**30**	7-43
System Failure Probability (%)	-	27	19	27	8	10	7	10	**15**	7-27

The nine subfactors of the attribute Physical Stress and Fatigue (Question 4) are shown in Table 5. Again, the large number of subfactors results in the averages that are

smaller. The only subfactor that is much higher or lower than the average expected value is the subfactor *physical difficulty of system operation*, which was much lower than average. The remaining averages are all very close to the average expected values.

Table 5: RELATIVE IMPORTANCE OF PHYSICAL STRESS AND FATIGUE SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Length of Operational Involvement (%)	-	10	18	13	17	15	2	12	12	2-18
Cumulative Time Engaged (%)	-	10	18	13	7	4	2	15	10	2-18
Physical Difficulty of System Operation (%)	-	12	8	9	7	5	2	2	6	2-12
Level of Health (%)	-	17	18	9	10	5	23	9	13	5-23
Environment (%)	-	10	5	11	10	15	23	12	12	5-23
Level of Protective Gear (%)	-	15	18	14	12	15	2	14	13	2-18
Sleep Prior to Operation (%)	-	8	10	10	13	13	19	14	12	8-19
Sleep During Operation (%)	-	8	2	10	12	15	11	11	10	2-15
Availability of Food and Water (%)	-	10	3	11	12	13	16	11	11	3-16

Table 6 shows the opinions of the subject matter experts on the seven subfactors of the attribute Mental Stress (Question 5). The subfactors *enemy threat level, systems training level, system experience level,* and *command level* were considered to be equally important by the participants, on average. This is consistent with the importance attached to the first three of these subfactors as determined for the attributes Attention Level and Workload earlier.

Table 7 contains the questionnaire results for the four subfactors of the attribute Vigilance Level (Question 6). For this attribute, none of the subfactors was judged to be greatly more important than the rest. There were small differences, but nothing more than 5% from the expected average.

Table 6: RELATIVE IMPORTANCE OF MENTAL STRESS SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Enemy Threat Level (%)	-	21	20	19	27	6	5	18	17	5-27
System Training Level (%)	-	5	20	15	17	25	23	15	17	5-25
System Experience Level (%)	-	5	16	15	17	25	23	20	17	5-25
Command Level (%)	-	21	11	13	13	22	23	15	17	11-23
Time Available (%)	-	15	16	15	13	10	16	13	14	10-16
System Failure Probability (%)	-	15	11	13	3	6	5	6	8	3-15
Personal Stress (%)	-	18	6	10	10	6	5	13	10	5-18

Table 7: RELATIVE IMPORTANCE OF VIGILANCE LEVEL SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Length of Operational Involvement (%)	-	32	25	27	26	24	30	34	28	24-34
Sleep Prior to Operation (%)	-	18	25	27	29	24	40	21	26	18-40
Sleep During Operation (%)	-	27	5	23	26	24	20	21	21	5-27
Distractions (%)	-	23	45	23	19	28	10	24	25	10-28

2. Survey Results for Attribute Importance

Table 8 provides the results of Survey Question 7, "To what extent do the following **attributes** affect *Target Acquisition*, given that the Target is visible." The attributes are weighted as to the percentage of importance of the attribute to the overall search and acquisition task.

As shown in the table, the attribute Attention Level was considered to be very important to the target acquisition task by the survey participants. The attribute Vigilance Level was also considered to be of higher than average importance. The numerical order of

importance of the six attributes to the search and acquisition task, as determined by the survey participant's was:

- Attention Level (25%)
- Vigilance Level (19%)
- Distraction (15%)
- Workload (14%)
- Physical Stress and Fatigue (13%)
- Mental Stress (12%)

Table 8: RELATIVE IMPORTANCE OF ATTRIBUTES FOR *TARGET ACQUISITION*

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Attention Level (%)	-	27	38	21	16	21	37	17	25	16-38
Distraction (%)	-	16	12	15	22	19	7	15	15	7-22
Workload (%)	-	4	12	15	10	17	20	20	14	4-20
Physical Stress and Fatigue (%)	-	12	5	17	14	19	7	17	13	5-19
Mental Stress (%)	-	16	12	15	19	5	7	11	12	5-19
Vigilance Level (%)	-	25	21	17	19	19	22	20	19	17-25

3. Survey Results for Linguistic Variable Levels

Table 9 records the results Question 8. This question asked the participants, "Using a scale of 0 - 100, with 100 representing the maximum possible and 0 the minimum possible, indicate the number which best fits the following descriptors as they relate to an Observer's probability of target acquisition." The responses provide a measure of the peak values for each of the seven linguistic variables used in this study. These values are not used for the actual prototype program fuzzy sets because of the possibility of gaps or skewed sets. They are useful, however, in showing why a fuzzy logic based model is appropriate. Each of the participants provided different values for the seven linguistic variables. This shows the differences in the meanings attached to the linguistic variables by the individual participants and thus the ambiguity which must be overcome by any definition of the

linguistic variables. Fuzzy logic is very good for working with such imprecise data definition and therefore has been a good choice for the prototype program.

Table 9: LINGUISTIC VARIABLE VALUE LEVELS

Participant Number	1	2	3	4	5	6	7	8	Avg
Very High	-	95	100	90	90	70	95	90	90
High	-	80	82	80	80	90	60	80	79
Moderately High	-	67	65	80	70	80	50	75	70
Medium	-	50	52	70	50	90	50	70	62
Moderately Low	-	35	25	50	30	60	40	40	40
Low	-	20	15	40	20	50	30	30	29
Very Low	-	5	5	40	10	30	20	20	19

C. RESULTS OF SECOND SURVEY

1. Survey Results for Subfactor Importance

The following tables record the results of the second administration of the survey, as described above. This second survey was administered to the eight participants after the evaluation exercise was completed.

Table 10 shows the results for the first survey question dealing with the importance of the four subfactors for the Attention Level attribute. The participants considered the subfactor *enemy threat level* to be much more important than the other subfactors. They judged this one subfactor to account for over half the total attribute's effect on performance.

Table 10: RELATIVE IMPORTANCE OF ATTENTION LEVEL SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Operational Workload (%)	10	10	17	26	10	30	24	0	16	0-30
Enemy Threat Level (%)	70	50	44	32	80	50	47	80	57	32-80
Positive Unit Interactions (%)	10	20	22	21	5	10	11	5	13	5-22
Personal Stress (%)	10	20	17	21	5	10	18	15	14	5-21

Survey results for the seven subfactors of the attribute Distraction (Question 2) are shown in Table 11. The subfactors *operational intensity* and *enemy threat level* were considered to have a large effect on Attention Level The subfactor *extraneous distractions* was also judged to have a higher than average effect. At the other end of the scale, the subfactors *system failure probability* and *negative unit interactions* were considered to have a lower than average effect on this attribute.

Table 11: RELATIVE IMPORTANCE OF DISTRACTION SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Operational Intensity (%)	20	10	19	12	60	8	17	10	20	8-60
Enemy Threat Level (%)	20	20	19	17	5	8	23	70	23	5-70
System Failure Probability (%)	10	10	6	15	5	8	12	0	8	0-15
Negative Unit Interactions (%)	10	10	3	12	5	8	7	0	7	0-12
Combat Experience Level (%)	20	20	19	15	0	13	7	10	13	0-20
Combat Training Level (%)	10	10	19	15	5	13	27	5	13	5-27
Extraneous Distractions (%)	10	20	15	14	20	42	7	5	17	4-42

The ratings for the four subfactors of the attribute Workload (Question 3) are shown in Table 12. The subfactors *systems training level* and *systems experience level* both received high ratings from the survey participants.

Table 12: RELATIVE IMPORTANCE OF WORKLOAD SUBFACTORS

Participant number	1	2	3	4	5	6	7	8	Avg	Range
Number and Complexity of Systems (%)	20	60	29	24	10	14	18	10	23	10-60
Systems Training Level (%)	20	10	29	24	15	46	36	50	29	10-50
Systems Experience Level (%)	10	10	29	28	70	32	36	25	30	10-70
System Failure Probability (%)	50	20	13	24	5	8	10	15	18	5-50

The nine subfactors of the attribute Physical Stress and Fatigue (Question 4) are shown in Table 13. The subfactor *length of operational involvement* was the only subfactor

with a weighting greater than the expected average by a large margin, accounting for 17% of the total effect of this attribute where the average expected value is 11%. All other subfactors are within 3% of this expected value.

Table 13: RELATIVE IMPORTANCE OF PHYSICAL STRESS AND FATIGUE SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Length of Operational Involvement (%)	20	9	13	11	40	15	12	15	17	9-40
Cumulative Time Engaged (%)	10	18	16	12	10	3	14	15	12	3-18
Physical Difficulty of System Operation (%)	10	18	2	11	5	2	10	2	8	2-18
Level of Health (%)	10	5	13	10	5	3	15	8	9	3-15
Environment (%)	10	5	13	11	10	12	15	5	10	5-15
Level of Protective Gear (%)	10	9	13	12	10	14	2	20	11	2-20
Sleep Prior to Operation (%)	10	9	14	11·	10	17	12	15	12	9-17
Sleep During Operation (%)	10	18	8	11	5	17	1	15	11	1-18
Availability of Food and Water (%)	10	9	8	11	5	17	19	5	10	5-19

Table 14 shows the ratings given to the seven subfactors of the attribute Mental Stress (Question 5) by the survey participants. The subfactor *enemy threat level* was considered by the participants to be very important to the total effect of this attribute, whereas the subfactor *system failure probability* was judged to be of lower than average importance.

Table 15 contains the results for the four subfactors of the attribute Vigilance Level (Question 6). None of the subfactors for this attribute were greater then 3%from the expected average value of 25%.

Table 14: RELATIVE IMPORTANCE OF MENTAL STRESS SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Enemy Threat Level (%)	20	20	18	16	42	6	19	75	27	6-75
System Training Level (%)	10	10	18	14	16	26	19	5	15	5-26
System Experience Level (%)	10	10	18	14	16	19	19	5	15	5-19
Command Level (%)	10	10	9	16	5	6	17	0	9	0-17
Time Available (%)	20	30	18	16	11	32	17	2	18	2-32
System Failure Probability (%)	10	10	9	14	5	5	4	3	8	3-14
Personal Stress (%)	20	10	10	10	5	6	5	10	10	5-20

Table 15: RELATIVE IMPORTANCE OF VIGILANCE LEVEL SUBFACTORS

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Length of Operational Involvement (%)	50	10	25	28	20	9	47	30	27	9-50
Sleep Prior to Operation (%)	10	10	25	22	60	31	35	30	28	10-60
Sleep During Operation (%)	30	30	25	22	10	31	6	30	23	6-31
Distractions (%)	10	50	25	28	10	29	12	10	22	10-50

2. Survey Results for Attribute Importance

Table 16 contains the results of Survey Question 7, which deals with the importance of the attributes to the search and acquisition task. As shown in the table, the attribute Attention Level was considered to be the most important to the target acquisition task by the survey participants. The attributes Physical Stress and Fatigue, Distraction, and Vigilance Level were also rated as being of higher than average importance. The numerical order of importance of the six attributes to the search and acquisition task, as determined by the survey participants, was:

- Attention Level (22%)
- Vigilance Level (19%)
- Physical Stress and Fatigue (18%)
- Distraction (17%)
- Workload (12%)
- Mental Stress (12%)

Table 16: RELATIVE IMPORTANCE OF ATTRIBUTES FOR *TARGET ACQUISITION*

Participant Number	1	2	3	4	5	6	7	8	Avg	Range
Attention Level (%)	11	20	29	19	40	26	14	20	**22**	11-40
Distraction (%)	11	20	24	17	20	8	14	25	**17**	8-25
Workload (%)	11	10	9	15	5	9	30	5	**12**	5-30
Physical Stress and Fatigue (%)	22	30	15	15	15	26	14	5	**18**	5-30
Mental Stress (%)	22	10	9	15	10	8	14	5	**12**	5-22
Vigilance Level (%)	22	10	14	19	10	23	14	40	**19**	10-40

3. Survey Results for Linguistic Variable Level

Table 17 records the results of the final survey question, Question 8. This question asked the participants to specify the number between 0 and 100 that best describes the seven linguistic variables used for this study.

Table 17: LINGUISTIC VARIABLE VALUE LEVELS

Participant Number	1	2	3	4	5	6	7	8	Avg
Very High	90	95	90	100	90	95	80	70	**89**
High	80	85	80	90	80	85	70	60	**79**
Moderately High	70	70	60	70	60	75	60	50	**64**
Medium	60	50	50	40	50	70	50	40	**51**
Moderately Low	40	30	20	10	30	65	40	30	**33**
Low	30	15	13	0	20	50	30	20	**22**
Very Low	20	5	3	0	10	40	20	10	**14**

D. SURVEY COMPARISON

The two surveys whose results are recorded in this study were completed by the same group of subject matter experts. However, the results of the two surveys differ for many of the subfactors of each attribute. Even in the final ranking of attribute importance itself, the results are different for half the attributes. Since the participants were the same for both surveys, this is unexpected.

The ranking differences occurred most notably in the subfactor ratings for the attributes with a large number of subfactors, e.g., Physical Stress and Fatigue, Distraction, and Mental Stress. Differences in percent importance occurred for most subfactors and attributes. The linguistic variable value scores were also different, some by a large margin. A breakdown of the major differences in importance rankings for the subfactors and the attributes follows.

1. Comparison of Subfactor Rankings

For the four subfactors of the attribute Attention Level, *enemy threat level* was ranked as the most important for both surveys. *Operational workload* increased in rank from third to second from the first survey to the second survey. *Personal stress* also increased in the second survey, from least important to third in importance. *Positive unit interactions* declined from second in importance in the first survey to least important in the second survey.

The seven subfactors of the attribute Distraction changed their importance ranking significantly from the first survey to the second. Second survey ranking was (1) *enemy threat level,* up from sixth in first survey, (2) *operational intensity*, which was third previously, (3) *extraneous distractions*, down from most important to third in importance, (4) *combat experience level*, increased from fifth to fourth in importance, (5) *combat training level*, decreased from second most important to fifth most important, (6) *system failure probability*, which increased from least important to sixth out of seven, and (7)

negative unit interactions, which decreased from fourth to seventh (least) in importance from the first survey to the second survey.

For the four subfactors of the attribute Workload, two of the most important subfactors changed positions. The ranking of these subfactors after from the second survey are as follows: (1) *system experience level*, which was second of four in the first survey, (2) *system training level,* from most important in the first survey to second in the second survey, (3) *number and complexity of systems*, and (4) *system failure probability*. The two least important subfactors did not change ranking between the first and second survey.

For the attribute Physical Stress and Fatigue, the nine subfactors were ranked much differently in the first and second surveys. Ranking of the four most important subfactors after the second survey was: (1) *length of operational involvement*, changed from third in importance to the most important from the first to the second survey, (2) *cumulative time engaged*, ranked seven of nine in the first survey but second of nine in the second survey, (3) *sleep prior to operation*, which increased in importance from fifth to third of nine, and (4) *level of protective gear*, which decreased from second in importance to fourth in importance between the two surveys. The remaining five subfactors were ranked as follows: (5) *sleep during operation*, increased from eighth of nine to fifth, (6) *environment,* decreased from fourth to sixth in importance, (7) *availability of food and water*, dropped from sixth to seventh most important, (8) *level of health*, judged to be the most important subfactor in the first survey, but in the second ranked only eighth of nine (a very large change), and (9) *difficulty of system operation*, ranked as least important in affecting an observer's physical stress and fatigue in both the first and second surveys.

The seven subfactors of the attribute Mental Stress showed numerous small changes in ranking between the two surveys. Only the subfactor *time available* showed a relatively large change in importance. The ranking for this attribute's subfactors is as follows after the second survey: (1) *enemy threat level* was considered to be the most important in affecting the Mental Stress level of an observer in both surveys, (2) *time available* increased from fifth of seven subfactors to the second most important, (3) *system*

training level decreased from second in rank to third, (4) *system experience level* was judged to be the fourth most important subfactor in the second survey and the third most important in the first survey, (5) *personal stress* increased from sixth to fifth in ranking, (6) *command level* decreased in importance from fourth to sixth most important and (7) *system failure probability* was determined to be the least important in both surveys.

Ranks of Vigilance Level subfactors all changed between the two surveys but, as with the attribute Workload, none changed by more than one position. The second survey ranking of these subfactors was: (1) *sleep prior to operation*, increased from second to first in importance, (2) *length of operational involvement*, which dropped from being the most important to being second in importance between the surveys, (3) *sleep during operation*, increased from least importance to third of four, and (4) *distractions*, considered less important in the second survey, falling from a ranking of third to a rank of fourth.

2. Comparison of Attribute Rankings

The attribute rank changed for half of the attributes from the first survey to the second survey. It is interesting to note that the first, second, and least important attribute ranking remained the same for both surveys. Ranks of the remaining three attributes changed, but not by large amounts. This shows a relatively consistent determination of importance by the survey participants for both surveys.

The attributes ranked as the top three in the second survey were: (1) Attention Level, which was determined to be the most influential attribute affecting the target acquisition performance of an observer in a combat situation in both surveys, (2) Vigilance Level, judged to be second most important in both surveys and, (3) Physical Stress and Fatigue, ranked as fifth most important in the first survey and third in the second survey. The remaining three attributes were ranked as follows: (4) Distraction, judged third most important in the first survey and fourth in the second. (5) Workload, ranked fourth in the first survey but only fifth in the second and, (6) Mental Stress, which was considered to be least important in its effect on target acquisition performance in both surveys.

3. Comparison of Linguistic Variable Values

The last survey question asked the participants to pick the number, in the range 0-100, that best described each of the seven linguistic variables used in this study. The resulting average values for these variables changed significantly between the two surveys. This reinforces the decision not to utilize these values as the center (or peak) values for the fuzzy sets used in the prototype program. The average values are shown in Table 18 for each linguistic variable, for both the first and second survey.

Table 18: LINGUISTIC VARIABLE AVERAGE VALUES

Survey Number	1	2
Very High	90	89
High	79	79
Moderately High	70	64
Medium	62	51
Moderately Low	40	33
Low	29	22
Very Low	19	14

4. Possible Explanations of Survey Differences

Because the same survey was administered to the same group soldiers both times, the results were expected to be very similar. Although not all participants showed large changes in their judgements of the subfactor importances, enough did to produce greater than expected differences. The average amount of change for the seven soldiers who completed both surveys was 7% per subfactor. The lowest average change was 1.6% for one soldier, the highest was 11.8% for another. Several explanations for these changes are possible.

First, the participants may have changed their determinations based on the exercise that they had recently completed. While this exercise may or may not have added

much to their individual opinions, it may have brought experiences back to memory that had not been considered for the first survey. This remembering of past events may have been applied to the second survey and resulted in changed judgements.

A second possibility may be that the scenarios to which the questions applied were presented differently for the two surveys. The two administrators may have given different explanations of what the subfactors and attributes were and how they relate to target acquisition. Making judgements based on different scenarios could well have produced different responses to the questions.

A third possibility is that some participants did not actually apply their past experiences and completed the survey only because they had been told to. A lack of interest in the survey or a feeling that their time could be better spent elsewhere may have resulted in survey answers given in a random or semi-random fashion.

A fourth possibility is that most individuals have no firm, fixed opinions on the relative importance of psychological attributes such as Attention and Vigilance. Participants may have taken the surveys seriously, but the task assigned them was a very difficult one unless they had previously spent time considering what human factors had affected their individual performance and the implications of the different attributes and subfactors with regard to the target acquisition task. In the absence of previous thoughtful consideration, it would have been remarkable for each participant to provide consistent answers throughout. In fact, the degree of consistency was surprisingly good.

Whichever explanation may be responsible for the differences in the results of the two surveys, the sample size was nonetheless much too small for reaching definite conclusions about the relative importance of factors affecting target acquisition. Additional surveys of similar subject matter experts will be required before this is possible. Until these future surveys can be completed, the results of this study can be used to provide trend information and an idea of rank orders.

V. FUZZY LOGIC MODEL DESCRIPTION

A. JANUS (A) TARGET ACQUISITION MODIFICATION

The goal of this study is to provide an improved model of target acquisition that includes human factors that may affect the ability of an observer to detect and identify targets. The model is based on data collected from questionnaires completed by subject matter experts, the personal experiences of the author, and collected experiences of JANUS (A) program managers. A fuzzy logic approach has been used for the reasons discussed in Chapters I and II. The Army's JANUS (A) combat simulation system is the proposed vehicle for testing and incorporation of the proposed model. The aim of this study is not to replace the entire JANUS (A) target acquisition model, but to modify certain portions of it to account for the human factors described earlier. The source code for the prototype human factors program which will supply the modifications is given in Appendix B.

The proposed fuzzy logic model is designed to interact with the JANUS subroutine which sets the initial level of detectable cycles for individual units, that is, which defines the apparent size and contrast of a target that is required for the observing unit to be able to detect that particular target. This subroutine is called INITACQ in the current JANUS (A) system. It determines an initial number of cycles for a given target based on a randomly generated number, as described in Chapter I.

As discussed below, the final product of the fuzzy logic human factors model is a crisp number between 0.0 and 1.0. It is proposed that this crisp number be incorporated into the current JANUS (A) target acquisition model in the initialization phase of a JANUS (A) simulation run. The fuzzy logic model output would serve as a modification to the threshold number of resolvable cycles that is computed for each sensor-target pair in the subroutine INITACQ.

The INITACQ threshold number could be modified in two ways The first would be to divide the resolvable cycles (produced by the current procedure) by the result of the human factors program. When the output of the human factors model is less than 1.0, this would increase the number of resolvable cycles required across a target before it could be considered for the sensor's potential target list. This process would simulate lowering the performance of the sensor because of the performance degradation effects of human factors. A problem with this method is that each sensor-target pair receives a threshold number of resolvable cycles by the generation of a random number. This means that two sensors of the same type may have large differences in the threshold number of resolvable cycles even before the consideration of additional factors.

A second modification technique would be to replace the random number of resolvable cycles with a base number of resolvable cycles that would be used by all sensors of a specific type. This base number could then be modified by dividing it by the output of the human factors program. A suggested value for this base number of resolvable cycles is 1.0. This number would result in a value of 0.5 for the probability of detection by an arbitrary group of observers [Ref. 1]. A related option would be to have the user specify a base number for each sensor type during initialization. Alternatively, a random base number could be assigned, as is done currently, but the base number could be generated for each specific sensor type rather than for each individual sensor-target pair.

B. COMPUTER IMPLEMENTATION

The current implementation of the proposed fuzzy logic human factors model is written in the *Common LISP* computer language. A menu system has been written for both the Star Sapphire Common LISP and the Allegro Common LISP implementations, each with program-specific function calls, and will not operate under other Common LISP implementations. This does not affect the actual operation of the fuzzy logic program, but it does prevent the use of the menu system with other Common LISP interpreters. The

following discussion assumes that the prototype system is running under the Star Sapphire Common LISP interpreter.

The Common LISP language was chosen for this program because prototyping is easier due to LISP's interpreted operation and its high-level design. However, due to its method of retrieving memory that is no longer being used by the program (referred to as "garbage collection"), Common LISP is not considered suitable for real-time simulation applications. Neither is it desirable to have a separate language running for such a small part of the simulation, since the rest of the JANUS (A) simulation is written in the FORTRAN programming language.

Because of these considerations, it may be desirable eventually to rewrite the current implementation in FORTRAN. This should not be hard since the Common LISP function definitions are relatively small and Common LISP can normally be converted to another high-level language, such as FORTRAN or C or C++, with considerable ease.

Changing the existing JANUS (A) program to utilize the fuzzy logic model should be relatively easy. Modification could consist of a call to the proposed model's program as a subroutine and division of the base number (or any number desired by the implementor) by the output returned from the subroutine call.

Because the fuzzy logic human factors model program is written as a completely separate program, it need not be inserted in its entirety into the existing simulation program. The model could be used as a stand-alone process that is initiated by the existing target detection simulation program. Its result can be passed back to the existing program for use in modifying the INITACQ output before continuing with the initialization phase of the simulation.

C. FUZZY LOGIC MODEL OPERATION

1. Program Initialization

The fuzzy logic model program requires that a Common LISP interpreter be operating for it to run, in the current configuration. Once the interpreter is running, the file

FSTART.LSP must be loaded. This file then loads the program files FUZZY.LSP and MENU.LSP, which contain the fuzzy logic and menu functions.

After the file FSTART.LSP is loaded, and after it loads the FUZZY.LSP and MENU.LSP files, the program is started by calling the function *startMenu.* In a LISP environment, a function is called by placing its name and any necessary arguments inside parentheses, e.g., *(startMenu).* In the fuzzy logic program, once this function call is made the program is controlled entirely from the menu system. Desired options are selected by entering the associated menu number or letter. Each menu selection takes the user to another menu level or to an entry screen where inputs can be entered. Figure 7 shows an example of the top level menu associated with the fuzzy logic program.

```
TOP MENU

1. Final Output Menu

2. Attribute Menu

A. Exit and Compute Final Output
```

Figure 7: Example Top Menu

As shown in Figure 7, to select the entry for entering a final output value directly (without any computation by the fuzzy logic program), a 1 should be entered. To enter attribute or subfactor weights and linguistic values, the number 2 should be entered. The letter A exits the program and computes the final output based on the values entered by the. user

2. User Inputs

The user first specifies which of the six attributes or their related subfactors is to be defined (see Figure 8). Model inputs consist of typing in a numerical weight for the specified attribute or subfactor, an abbreviation for the desired linguistic value for that same attribute or subfactor, or both. Case and order of entry are not important as the program can handle any order or case. Input is terminated by pressing the return or enter

key. The user is then returned to the menu for selection of another attribute or subfactor, if desired.

For an attribute, the weight that is entered represents the importance or contribution of that attribute to the overall target acquisition performance level. The output is a single number in the range [0-1]. For a subfactor, the weight represents the importance or contribution of that subfactor to the attribute of which it is a part. For example, a weight of 0.5, if applied to an attribute, would make that attribute responsible for half of the total output number produced by the program If applied to a subfactor, it would make that subfactor responsible for half of the value of the applicable attribute. The contributions of the remaining subfactors would then sum to 0.5.

Attribute Weights and/or Values Menu

1. "Attention Level"
2. "Distraction Level"
3. "Workload"
4. "Physical Stress and Fatigue"
5. Mental Stress"
6. "Vigilance Level"

A. Return to Previous Menu

"Attention Level"	nil	nil
"Distraction Level"	nil	nil
"Workload	nil	nil
"Physical Stress and Fatigue"	nil	nil
"Mental Stress"	nil	nil
"Vigilance Level"	nil	nil

Figure 8: Example Attribute Menu

The linguistic values used for this model are the values *Very Low, Low, Moderately Low, Medium, Moderately High, High*, and *Very High* (abbreviated as *VL, L, ML, M, MH, H*, and *VH* for input into the program). These linguistic values represent the

level of the attribute or subfactor that is affecting the performance of the unit or individual. Input entry order or case is not important, but it is important that the linguistic value entered be one of the specified seven values. If not, an error is signalled and the program returns the user to the menu from which the entry was selected.

The linguistic values are combined using the fuzzy union operation, described in Chapter II, to produce a final fuzzy set representing the current performance state of the unit or individual, based on the modeled human factors. This final fuzzy set is then defuzzified to produce an overall level of target acquisition performance. The final output is a crisp number that represents a level of performance less than or equal to the best possible performance. In other words, an output of 1.0 indicates that the unit is performing as well as it is possible for it to perform, based on the human factors modeled. As the output will usually be some value less than 1.0 (though this is determined by the user) this resulting number represents the degrading effects of human factors on the overall performance of the unit, as the model is currently implemented.

a. Setting Attribute Weights and Linguistic Values

If desired, the subfactors for any or all attributes can be ignored and weights and linguistic values for the attributes themselves may be input (see Figure 9). Weights for the attributes should be input even if subfactor weights and values have also been input, unless the default weights are desired (see below). Setting the weights is necessary for determining the percentage of the resultant fuzzy set due to each individual attribute.

When setting the values for the weight and linguistic variable value of an attribute, the entry can consist of either (1) both weight and linguistic value, (2) weight alone, (3) linguistic value alone, or (4) neither weight nor linguistic value. If either or both of the entries are omitted, the unentered part is set to the program's default value. For the linguistic value, the default value is *Medium, M.* For the weight, the default value is based on the number of other attributes for which no weight value has been set. The weight used is equal to 1.0 minus the total of the weights that have been set, with this amount divided

by the number of unentered weights. For example, if values have not been set for four of the six attributes, and the two that are set have a total weight of 0.5, then the default weight for one of the attributes not already set would be (1.0 - 0.5) / 4, or 0.125. If no attribute weights have been set, the default values are the same as those that were determined from the survey administered to subject matter experts and described in Chapter IV.

Subfactor Menu for "Attention Level" Attribute

1. "Workload"
2. "Threat Level"
3. "Positive Crew Interaction"
4. "Personal Stress"

A. Return to Previous Menu

"Workload"	nil	nil
"Threat Level"	nil	nil
"Positive Crew Interaction"	nil	nil
"Personal Stress"	nil	nil

Figure 9: Example Subfactor Menu

After data entry, the value of the linguistic variable may appear to be different from the input value in the display of the values for all the attributes. Some attributes have a negative impact on performance while others have a positive impact. If the attribute has a positive impact, the linguistic variable value will be the same as that which is entered by the user. If the attribute has a negative impact, the displayed entry will have a value equal to the reciprocal of the input value. For example, the reciprocal of *VL* is considered to be *VH*, for *MH* the reciprocal is *ML*, etc. With input values of 0.5 and *VL*, if the attribute has a positive impact on performance, the values set by the program will be 0.5 and *VL*. If it has a negative impact, the values set will be 0.5 and *VH*. This process is used because the program computes the final output value based on the best possible performance. The determination of which attributes and subfactors have positive and which

have negative impacts on performance was determined during previous research and data collection (Chapters III and IV). The positive and negative values cannot be changed from the menu system in the current implementation, but could be added in a future implementation, if desired.

The user may change an already-entered value of an attribute by selecting that attribute from the appropriate menu (see Figure 8). Both the weight and the linguistic value for that attribute must be reentered, even if only one of them is to be changed; otherwise the default value will be set for the value not reentered. For example, if an attribute is set to a weight of 0.3 and a linguistic value of *VL* and the weight is to be changed, the linguistic value must also be reentered, else the default linguistic value of *M* will be set for that attribute's linguistic value when the weight is changed.

b. *Setting Subfactor Weights and Linguistic Values*

An example menu for selecting the subfactors of an attribute is shown in Figure 9. The subfactors are different for each attribute but the format is the same. The total of the subfactor weights for each attribute is 1.0. This assumes that each subfactor plays some part in defining the total importance of the attribute. A weight of 0.0 can be assigned if it is desired not to include a particular subfactor in the attribute. In the case where subfactor levels and weights are input, the attribute weights are still required even though the model computes attribute levels based on subfactor levels and weights.

The user has the capability to set the weights and linguistic values of each subfactor for any of the attributes, if that is desired. The entry procedure is the same as described above for the attributes. The default linguistic values of the subfactors are the same as for the attributes. However, the current default weights depend on the number of subfactors and the number for which weights have not been set, for a particular attribute. The procedures for changing subfactor weights or linguistic values is the same as for attributes.

c. Setting a Single Output Value

It is possible for the user to specify a single number in the range [0-1] for the final output value of the human factors model through the menu system (see Figure 10). The entry of a single linguistic variable value is also possible. This single linguistic value is then defuzzified to give the final output value. The user can thus set predetermined levels of performance without having to set values for each of the attributes or subfactors. To set either a single numeric or linguistic value for the final output, the appropriate menu entry is chosen and the number or linguistic value is input. The range of numbers, [0-1], and the set of linguistic values described above are used.

Final Output Menu
1. Enter Final Output as a Numeric Value
2. Enter Final Output as a Linguistic Value
A. Return to Top Menu

Figure 10: Example Final Output Menu

d. Input Options

If the user desires, weights and linguistic values for a combination of subfactors and attributes may be specified. If the user sets both the attribute values and all of the subfactor values for that attribute, the subfactor values are used to determine the attribute values, and any input linguistic value for that attribute is ignored. If some but not all of the subfactor values are set, the attribute values that have been set for that attribute are used. If either none or only some of the subfactor values have been specified by the user, and the attribute values have also not been specified, the program sets the attribute values to the default values for its calculation of the final output.

3. Final Output Calculation

Once all desired weights and linguistic values for subfactors and attributes have been input, the model converts each input into a representation of the fuzzy set associated with the input linguistic value. For example, if the input linguistic value for an attribute were *ML,* the attribute would be assigned a value of the fuzzy set representing the *Moderately Low* fuzzy set. This set would look like this prior to weighting.

Attribute Set = {0/0, 0/1, 0.35/2, 0.85/3, 0.65/4, 0.15/5, 0/6, 0/7, 0/8, 0/9, 0/10}. (5.1)

Next, the weight of the subfactor or attribute is used by the model to convert this fuzzy set into a weighted fuzzy set that describes both the linguistic value and weight of the subfactor or attribute. This is done by multiplying each membership value of the original fuzzy set by the weight value. For the attribute set shown above, the resultant set would look like this with a weight input of 0.5

Weighted Set = (0/0, 0/1, 0.175/2, 0.425/3, 0.325/4, 0.075/5, 0/6, 0/7, 0/8, 0/9, 0/10}. (5.2)

This process is repeated until all of the attributes and subfactors have been processed. Any subfactor or attribute for which values are not entered by the user is assigned the default values as described above.

a. Determination of Fuzzy Sets

Once the values for the subfactors and attributes have been set by the user or the default values have been assigned, the program computes the resulting fuzzy sets. Sets are calculated for each subfactor if all subfactors for an attribute have been entered, or for the attribute otherwise.

For example, consider the attribute fuzzy set for the attribute Vigilance Level, as defined by the subject matter expert survey (Chapter IV). This attribute has subfactors of *Length of operational involvement*, denoted here as LOI, *Amount of sleep or rest prior to mission or operation*, SPM, *Amount of sleep or rest during mission or*

operation, SDM, and *Level of observer's distraction*, LOD. Based on the survey results, the weights for these sets would be: LOI = 0.27, SPM = 0.28, SDM = 0.23, LOD = 0.22. If the user entered linguistic values for these subfactors corresponding to LOI = M, SPM = H, SDM = ML, and LOD = L, the resultant fuzzy sets would look like this.

$$
\begin{aligned}
&LOI = \{0/0, 0/1, 0/2, 0/3, 0.135/4, 0.27/5, 0.135/6, 0/7, 0/8, 0/9, 0/10\}. \\
&SPM = \{0/0, 0/1, 0/2, 0/3, 0/4, 0/5, 0/6, 0.084/7, 0.228/8, 0.196/9, 0.056/10\}. \quad (5.3) \\
&SDM = \{0/0, 0/1, 0.08/2, 0.196/3, 0.15/4, 0.035/5, 0/6, 0/7, 0/8, 0/9, 0/10\} \\
&LOD = \{0.044/0, 0.154/1, 0.176/2, 0.066/3, 0/4, 0/5, 0/6, 0/7, 0/8, 0/9, 0/10\}.
\end{aligned}
$$

The fuzzy union operation is then applied to these four subfactor fuzzy sets to produce a single fuzzy set for the attribute *Vigilance Level* (denoted here by VGL). This fuzzy set would look like the following.

$$
\begin{aligned}
VGL = \{&0.044/0, 0.154/1, 0.176/2, 0.196/3, 0.15/4, 0.27/5, \\
&0.135/6, 0.084/7, 0.224/8, 0.196/9, 0.056/10\}.
\end{aligned} \quad (5.4)
$$

This process of attribute value determination is carried out for all attributes that have not had an attribute level and weight input or that have not had all subfactor weights and values specified by the user. If both subfactor linguistic values and weights have been specified and an attribute linguistic value has been input for the same attribute, the input subfactor linguistic values and weights are used and the attribute linguistic value is ignored. The final procedure of this section applies the attribute weight, using the method described above, to the calculated attribute fuzzy set.

b. *Determination of Final Resultant Set*

A final resultant fuzzy set is determined by taking the fuzzy union of all attribute fuzzy sets. This process is essentially the same as that described in the previous section for determining an attribute fuzzy set from its component subfactors fuzzy sets. If no values are entered for the subfactors of all the attributes and the default linguistic value of *Medium* is applied to each set, the final attribute fuzzy sets would look like those in

Equation 5.5. This assumes that the weights for the fuzzy sets are the same as the weights specified by the subject matter experts surveyed.

$$
\begin{aligned}
&\text{Attention Level} = (0/1, 0/2, 0/3, 0.11/4, 0.22/5, 0.11/6, 0/7, 0/8, 0/9, 0/10)\\
&\text{Distractions} = (0/1, 0/2, 0/3, 0.085/4, 0.17/5, 0.085/6, 0/7, 0/8, 0/9, 0/10)\\
&\text{Workload} = (0/1, 0/2, 0/3, 0.06/4, 0.12/5, 0.06/6, 0/7, 0/8, 0/9, 0/10) \qquad (5.5)\\
&\text{Physical Stress/Fatigue} = (0/1, 0/2, 0/3, 0.09/4, 0.18/5, 0.09/6, 0/7, 0/8, 0/9, 0/10)\\
&\text{Mental Stress} = (0/1, 0/2, 0/3, 0.06/4, 0/5, 0/6, 0/7, 0/8, 0/9, 0/10)\\
&\text{Vigilance Level} = (0/1, 0/2, 0/3, 0.095/4, 0.19/5, 0.095/6, 0/7, 0/8, 0/9, 0/10)
\end{aligned}
$$

Applying the fuzzy union operation to these attribute fuzzy sets yields a single resultant fuzzy set. This resultant set, which will be used to determine the final output of the program, would look like this.

$$\text{Resultant Fuzzy Set} = (0/0, 0/1, 0/2, 0/3, 0.11/4, 0.22/5, 0.11/6, 0/7, 0/8, 0/9, 0/10) \qquad (5.6)$$

c. *Defuzzification of Final Output*

After an overall resultant fuzzy set is obtained, the model must defuzzify this resultant set to produce a crisp, non-fuzzy numerical output that can be applied to the existing JANUS (A) target acquisition model. The final crisp output number which is returned from the human factors model program is not calculated until the program is exited through the menu system. If the program is exited without setting values for any attribute or subfactor and without specifying a final output value for either numerical or linguistic factors, the value returned is calculated by setting all of the attributes to the default settings and using these settings to determine the final output. The numerical output in the current implementation will be 0.5, in this case.

The method of defuzzification used here is the Center of Sums method as described in Chapter II. This method returns a real number that reflects the total value of the resultant fuzzy set. Using the example resultant set shown in Equation 5.6, the calculation would be done as shown in Equation 5.7.

$$\text{Final Output} = \frac{\sum_{i=0}^{10} membership\text{-}value(i) \cdot i}{\sum_{j=0}^{10} membership - value(j) \cdot 10} \tag{5.7}$$

The membership value for each element of the resultant set is multiplied by the element number itself and the results are added together. Next the membership values for each element are added together and then multiplied by 10. The first sum (the membership values multiplied by the element numbers) is then divided by the second sum (the membership values) to produce the final crisp output number. Equation 5.8 shows these operations and the calculation of the final output that would be the result.

$$\sum_{i=0}^{10} = ((0 \cdot 0) + (0 \cdot 1) + (0 \cdot 2) + (0 \cdot 3) + (0.11 \cdot 4) + \ldots + (0 \cdot 10)) = 2.2$$

$$\sum_{j=0}^{10} = (0 + 0 + 0 + 0 + 0.11 + \ldots + 0) \cdot 10 = 4.4 \tag{5.8}$$

Final Output = 2.2 / 4.4 = 0.5

This final crisp number represents the overall percentage of optimal target acquisition performance for a particular sensor or weapon system or observer. When applied to the current JANUS (A) target acquisition model in either of the two ways described earlier, a more realistic threshold number of resolvable cycles is provided for that sensor or weapon system or observer, when compared with the current unmodified target acquisition threshold output.

VI. CONCLUSIONS AND RECOMMENDATIONS

The goal of this study has been to provide an improved model of target acquisition that includes human factors that may affect the ability of an observer to detect and identify targets. The model is based on data collected from questionnaires provided to subject matter experts, Army personnel taking part in an evaluation exercise requiring the acquisition and identification of ground targets. A fuzzy logic approach has been used because of the inherent ambiguity of human factors in general and because of the ability of this type of approach to model ambiguous and vague data. The Army's JANUS (A) combat simulation system is the proposed vehicle for testing and incorporation of the proposed model. This research into human factors effects and fuzzy logic has resulted in a prototype computer program demonstrating the new model.

The study reported here has covered several broad topics that include fuzzy set theory, human factors performance effects, computer programming in the LISP language, and the JANUS (A) battlefield simulation system. Conclusions and recommendations based on this study are presented below.

A. CONCLUSIONS

Battlefield simulators such as the JANUS (A) system allow military commanders to practice tactical skills without the need for extensive real-life exercises. The advantages of these simulations in training and weapons development are efficiency and lower cost, when compared with live exercises and testing. In the JANUS (A) battlefield simulation system, the events which drive the simulation are themselves driven by the ability of a specific unit or sensor to detect enemy units with a specified degree of accuracy.

Recent advances in computer technology and methodology make the inclusion of more realistic models of simulated vehicles possible. It also makes possible the addition of previously unused models of other factors in the simulation of combat exercises. These

unincorporated models include the human factors performance models related to combat effectiveness, which have been widely documented. Inclusion of these human factors effects will add significant realism to a simulation by allowing specific human performance levels to affect simulations outcomes, instead of relying on purely random inputs or simple handicaps.

Inclusion of these factors is especially important in the area of search and acquisition tasks. The effects on the human operating the sensor of many internal and external factors has been well documented. Some of these effects can have very detrimental overall effects on human operator performance.

The effects of the factors thought to affect this combat performance tend to be highly individualized. Thus a fuzzy logic methodology is suggested for incorporating these human factors into a useful model. As shown in other areas where fuzzy logic has been successful, vague or imprecise values or elements (common in expressing human-related concepts) can be modeled. Fuzzy logic models can also be easily implemented as add-on subroutines with existing systems such as the current JANUS (A) target acquisition model.

This study has demonstrated the feasibility of such an approach for developing a stand-alone model of human target acquisition performance. The model takes into account six primary human factors: attention level, distractions, workload, physical stress and fatigue, mental stress, and vigilance level. Fuzzy logic has been used for model development, and programming was done using the LISP programming language. However, the prototype can easily be converted to another programming language, if necessary for incorporation as a component of JANUS (A).

The study has demonstrated the usefulness of obtaining the opinions of subject matter experts for program development, when other data was not available. Although only a preliminary survey could be carried out at this time, the results have been helpful. They enabled development of a prototype fuzzy logic model that reflects the experiences of active-duty soldiers, based on their own target acquisition experiences. The model represents a first step towards development of a comprehensive description of human

detection, recognition, and identification performance that takes human variables into account and can be used for prediction and planning.

B. RECOMMENDATIONS

This study has not ended the research and development needed for incorporation of human factors effects into the JANUS (A) battlefield simulation system. More research is required to determine the factors which most affect human performance. The factors included in this study should be used only as a starting list of possible factors. Additional surveys of appropriate subject matter experts are needed to determine the most critical factors and to add to or subtract from the attributes and subfactors proposed here.

The interrelations among attributes and subfactors needs to be examined, something that was not fully accomplished in this study. This can be done in conjunction with subject matter expert surveys which are proposed to enhance the list of important factors.

The prototype program developed for this study must be written in a computer language compatible with the existing JANUS (A) system. The structure of the program may need enhancements or changes to reflect the results of research into modified factors and factor interactions, as proposed above. The rewritten program code should also be optimized to provide the best possible performance of the program with the JANUS (A) system.

Use of the fuzzy set methodology for representing various human factors should be modified as necessary to account for structural changes that might be made to the program. However the concept of using fuzzy logic for these human factors is sound. Because of the advantages described in Chapters I and II, this should not be replaced with another methodology.

Incorporation of similar human factors effects into other simulation systems should be considered. Whenever systems simulate human operations, they will benefit from models of these effects, provided the simulations can be expanded to include them.

APPENDIX A.

SUBJECT-MATTER EXPERT SURVEY

This section includes the survey administered to U. S. Army subject matter experts at Fort Hunter-Liggett, CA.

Target Acquisition Questionnaire

The purpose of this questionnaire is to obtain the opinions of subject matter experts about specific *human factors* that may influence *target acquisition* during combat. Subject matter experts for this study include U.S. soldiers and marines taking part in training exercises or system evaluation exercises that involve the location and identification of targets.

This study is part of an ongoing effort to add more realism to the Army's JANUS battlefield simulation system. The proposed additions to the JANUS target acquisition model will simulate the effects of *human factors* on an *observer's ability to detect, recognize, and identify a target* that is within the observer's field of view and is physically detectable

Survey results will be used to create an improved model of target acquisition performance. That is, the present JANUS physical model will be enhanced by incorporating the information from this survey into an additional fuzzy logic model of human performance.

Return completed questionnaires in person or by mail to:

LT Marvin Miller
SMC 1411
Naval Postgraduate School
Monterey, CA 93943

Personal Information

1. Rank __________

2. Length of Service __________

3. Primary Military Specialty ______________________________

4. Secondary Military Specialty ______________________________

5. Years and Months Experience in Primary Specialty __________

6. Do You have Combat Experience?

YES NO

Background

Present models of target acquisition are based primarily on the physical factors that make target detection possible, such as target size, target-to-background contrast, and weather. Human factors are not included. We are developing an enhanced model of target acquisition performance that includes several human-related factors in addition to the standard physical factors. These factors include six **attributes** of the observer who is searching for the target:

- **Attention level**: For this survey the following definition of **Attention level** is being used. **Attention level** is the level of active concentration on the target acquisition task. It is the amount of conscious mental focus that is being used for the search and detection process.
- **Distractions**: For this survey the following definition of **Distractions** is being used. **Distractions** are other activities that the observer must deal with that detract from the time available for search and detection tasks.
- **Workload**: For this survey the following definition of **Workload** is being used. **Workload** is the complexity of the controls and displays necessary to operate, and the difficulty and complexity of maintaining, the observation equipment.
- **Physical stress and fatigue**: For this survey the following definition of **Physical stress and fatigue** is being used. **Physical stress and fatigue** is the physical effort and discomfort associated with use of the observational equipment and the physical health and fatigue of the observer using it.
- **Mental stress**: For this survey the following definition of **Mental stress** is being used. **Mental stress** is the imposed on an observer due to the mental requirements necessary to performance of his total task load. This task load is not limited to the observational tasks.
- **Vigilance level**: For this survey the following definition of **Vigilance level** is being used. **Vigilance level** is the level of alertness of the observer. This alertness need not be consciously directed toward anything in particular to be active. It is related to a general awareness of the surroundings, not focused but all encompassing.

Each of these six **attributes** is influenced by various *subfactors* that have been identified as contributing to or partly determining the levels or importance of the **attributes**. For example, **Attention level** is probably influenced by operational workload, proximity to enemy threats, crew interactions, and personal stress.

We need your judgements on two things:

- The *importance* of each of the identified *subfactors* in influencing the levels of the six observer **attributes**, relative to the other *subfactors* of the same **attribute.**
- The *importance* of each of the six major **attributes** for the overall target acquisition process during combat, relative to the other major **attributes**.

The relative importance of the attributes and factors may depend to some extent on the kind of combat mission. Thus, in making your judgements of importance, consider a typical ground combat mission such as the following:

- The observer is in the field as part of a ground combat unit, involved in a quick response action in a Third World country. The combined action also includes military units from other nations. The action is a protracted one, expected to last for weeks or months.
- Locations of targets in the combat area are not known, so active search is critical.
- The possible targets may include enemy tanks, APCs, or other vehicles. Rules of engagement require that a target be positively identified prior to engagement.
- The observer has available an advanced portable weapon such as the Javelin, but is relying primarily on direct vision to locate potential targets. The weapon's sensor system may be used for identification, if needed.

1. Please answer each of the following questions based on your experiences and personal opinions.

2. For each question, distribute a total of 100 points among the listed *subfactors* based on the contribution of each to the **attribute** listed.

Example: To what extent are Good Grades in School affected by the following.

Hard work	15
Natural ability	5
Luck	80
Personality	0
	Total = 100

1. To what extent is an Observer's Attention Level affected by the following.

Current operational workload __________
e.g., The number of concurrent operational tasks that must be performed in addition to the search task.

Level of enemy threat __________
e.g., The perceived probability of enemy contact. A higher perceived probability is regarded as increasing the observers attention level for this survey.

Interactions with other members of immediate unit __________
e.g., Crew coordination, the minimization of extraneous tasking of the observer by the actions of the other members of the crew, allowing the observer to concentrate on the search task.

Personal stress __________
e.g., Stress created by personal concerns, such as family, financial, career, etc., that distract the observer from the task at hand.

Total=100

2. To what extent do the following increase an *Observer's Distraction*.

Current operational intensity __________
e.g., Level of combat in the observers general area, not necessarily involving the observer.

Level of enemy threat __________
e.g., The perceived probability of enemy contact. A higher perceived probability is regarded as increasing the observers level of distraction for this survey.

Probability of observation system failure __________
e.g., perceived likelihood of equipment malfunction/failure.

Negative interactions with other members of immediate unit __________
e.g., The interruption of the observers concentration or tasking by the actions of the other members of the observers immediate crew.

Level of combat experience __________
e.g., Amount of prior time in combat operations, including operations where combat did not actually occur but was expected.

Level of combat training __________
e.g., Amount and sophistication of training for combat operations.

Target area extraneous distractions __________
e.g., Civilian or Friendly forces activity in observer's general area.

Total=100

3. To what extent do the following contribute to an *Observer's Workload*.

Number and complexity of search/weapons systems __________
e.g., Systems being used to perform the observation duties.

Level of training using search/weapons systems __________
e.g., Familiarity with, and knowledge of, the systems controls and displays.

Level of experience using search/weapons systems __________
e.g., Amount of hands-on time using current systems in realistic conditions.

Likelihood of observation system failure __________
e.g., perceived likelihood of equipment malfunction/failure.

Total=100

4. To what extent do the following factors affect an *Observer's Physical Stress and Fatigue*.

Length of operational involvement ____________
e.g., Time since start of current mission or operation.

Cumulative time engaged with enemy ____________
e.g., Total time engaged in combat with enemy forces since start of mission or operation.

Physical difficulty of operating search/weapon systems ____________
e.g., Actual physical effort required to operate the search equipment.

Level of Observer's general health ____________
e.g., Physical condition of observer, such as healthy, sick, injured, etc.

Environment ____________
e.g., Temperature, humidity, precipitation, etc.

Level of protective gear required ____________
e.g., Chemical protective clothing, or MOPP, level, etc.

Amount of sleep prior to mission or operation ____________
e.g., Amount of sleep or rest in the 36 hours preceding the start of the current mission or operation.

Amount of sleep or rest during mission or operation ____________
e.g., Total amount of sleep or rest since start of current mission or operation. Does not need to be continuous sleep or rest.

Availability of food and water ____________
e.g., Access to, and consumption of, food and water or other liquid that replaces lost body fluids.

Total=100

5. To what extent do the following factors affect an *Observer's Mental Stress*.

Level of enemy threat __________
e.g., The perceived probability of enemy contact. A higher perceived probability is regarded as increasing the observers level of mental stress for this survey.

Level of training using search/weapons systems __________
e.g., Familiarity with, and knowledge of, the systems controls and displays.

Level of experience using search/weapons systems __________
e.g., Amount of hands-on time using current systems in realistic conditions.

Observer's command level __________
e.g., Level of command authority. Not necessarily the rank of the observer.

Time available for search __________
e.g., perceived amount of time available for search. May correspond to the perceived urgency of the search task.

Likelihood of observation system failure __________
e.g., perceived likelihood of equipment malfunction/failure.

Personal Stress __________
e.g., Stress created by personal concerns, such as family, financial, career, etc., that distract the observer from the task at hand.

Total=100

6. To what extent do the following factors affect an *Observer's Vigilance Level*.

Length of operational involvement ____________
e.g., Time since start of current mission or operation.

Amount of sleep prior to mission or operation ____________
e.g., Amount of sleep or rest in the 36 hours preceding the start of the current mission or operation.

Amount of sleep or rest during mission or operation ____________
e.g., Total amount of sleep or rest since start of current mission or operation. Does not need to be continuous sleep or rest.

Level of Observer's distraction ____________
e.g., The attribute **Distraction** as defined above

Total=100

7. To what extent do the following **attributes** affect *Target Acquisition*, given that the Target is visible.

Observer's Attention Level ____________

Observer's Distraction ____________

Observer's Workload ____________

Observer's Physical Stress and Fatigue ____________

Observer's Mental Stress ____________

Observer's Vigilance Level ____________

Total=100

Using a scale of 0 - 100, with 100 representing the maximum possible and 0 the minimum possible, indicate the number which best fits the following descriptors as they relate to an Observer's probability of target acquisition.

Example:

(100)

Very High |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Low |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100
(10)

Very High |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

High |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Moderately High |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Medium |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Moderately Low |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Low |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

Very Low |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
0 50 100

COMMENTS

APPENDIX B

This section contains the complete source code for the fuzzy logic based human factors prototype program described in this study. The contents include the program variables and functions and the menu variables and functions of the files named FUZZY.LSP and MENU-ALL.LSP.

```
;;
;; Fuzzy Logic Human Factors Program
;; File Name: FUZZY.LSP
;; Author Marvin Miller, LT., USN
;; Date: 1 March 1994

;; Required to initialize and access
;; Allegro Common LISP screen routines.
(require :xcw)
(use-package :cw)

;; Variable used to build the fuzzy sets
;; used by the rest of the program.
;; Each of the composite sets is described
;; by an access name, followed by the position
;; of the peak value and the length of half the
;; base of the fuzzy set, assuming symmetric sets.

(setf setSizes '((VL 0.0 2.0) (L 1.6 2.0)   (ML 3.3 2.0)
                 (M 5.0 2.0)   (MH 6.7 2.0) (H 8.4 2.0)
                 (VH 10.0 2.0)))

;; Definitions for inputs.

(setf VL 'VL vl 'VL)
(setf L 'L l 'L)
(setf ML 'ML ml 'ML)
(setf M 'M m 'M)
(setf MH 'MH mh 'MH)
(setf H 'H h 'H)
(setf VH 'VH vh 'VH)
(setf n 'n p 'p)
```

```lisp
;; Place holders and general descriptions
;; of the fuzzy sets used by the program. The
;; actual membership values for the sets are
;; determined at the start of the program and
;; are dependent on the settings of the setSizes
;; variable described above.

(setf fuzzyVL '((1 0) (0.5 1) (0 2) (0 3) (0 4) (0 5) (0 6) (0 7) (0 8) (0 9) (0 10)))
(setf fuzzyL '((0.5 0) (1 1) (0.5 2) (0 3) (0 4) (0 5) (0 6) (0 7) (0 8) (0 9) (0 10)))
(setf fuzzyML '((0 0) (0 1) (0.5 2) (1 3) (0.5 4) (0 5) (0 6) (0 7) (0 8) (0 9) (0 10)))
(setf fuzzyM '((0 0) (0 1) (0 2) (0 3) (0.5 4) (1 5) (0.5 6) (0 7) (0 8) (0 9) (0 10)))
(setf fuzzyMH '((0 0) (0 1) (0 2) (0 3) (0 4) (0 5) (0.5 6) (1 7) (0.5 8) (0 9) (0 10)))
(setf fuzzyH '((0 0) (0 1) (0 2) (0 3) (0 4) (0 5) (0 6) (0 7) (0.5 8) (1 9) (0.5 10)))
(setf fuzzyVH '((0 0) (0 1) (0 2) (0 3) (0 4) (0 5)  (0 6) (0 7) (0 8) (0.5 9) (1 10)))



;; The following three functions are used to build
;; the actual fuzzy sets used in this program.

(defun computeWeight (element center base)
  (cond ((= element center) 1)
        ((< element center)
         (/ (- element (- center base)) base))
        ((> element center)
         (/ (- (+ center base) element) base))))

(defun computeSets (sizes set)
  (let ((tempLow (- (second sizes) (third sizes)))
        (tempHigh (+ (second sizes) (third sizes))))
        (dotimes (I (length set))
           (cond ((and (<= I tempHigh) (>= I tempLow))
                  (setf (car (nth I set))
                        (computeWeight I (second sizes)
                                         (third sizes))))
                 (t (setf (car (nth I set)) 0.0)))))
  set)
```

```
(defun initSets ()
  (setf finalOutput nil)
  (dotimes (J (length attributeList))
     (setf (second (nth J attributeList)) nil)
     (setf (third (nth J attributeList)) nil)
     (dotimes (L (length (nth J masterList)))
        (setf (second (nth L (nth J masterList))) nil)
        (setf (third (nth L (nth J masterList))) nil)))
  (dotimes (I (length setSizes))
     (cond ((eq (first (nth I setSizes)) 'VL)
             (setf fuzzyVL (computeSets (nth I setSizes) fuzzyVL)))
            ((eq (first (nth I setSizes)) 'L)
             (setf fuzzyL  (computeSets (nth I setSizes) fuzzyL)))
            ((eq (first (nth I setSizes)) 'ML)
             (setf fuzzyML (computeSets (nth I setSizes) fuzzyML)))
            ((eq (first (nth I setSizes)) 'M)
             (setf fuzzyM  (computeSets (nth I setSizes) fuzzyM)))
            ((eq (first (nth I setSizes)) 'MH)
             (setf fuzzyMH (computeSets (nth I setSizes) fuzzyMH)))
            ((eq (first (nth I setSizes)) 'H)
             (setf fuzzyH  (computeSets (nth I setSizes) fuzzyH)))
            ((eq (first (nth I setSizes)) 'VL)
             (setf fuzzyVH (computeSets (nth I setSizes) fuzzyVH))))))

;; Attaches fuzzy sets to variables based on the input
;; access name.

(defun initVars (fuzzyset)
  (case (eval fuzzyset)
        ('VL (setf temp (copy-alist fuzzyVL)))
        ('L  (setf temp (copy-alist fuzzyL)))
        ('ML (setf temp (copy-alist fuzzyML)))
        ('M  (setf temp (copy-alist fuzzyM)))
        ('MH (setf temp (copy-alist fuzzyMH)))
        ('H  (setf temp (copy-alist fuzzyH)))
        ('VH (setf temp (copy-alist fuzzyVH)))
        (nil nil)))
```

```
;; Inverts values based on positive or negative effects
;; of attribute or subfactor on performance.

(defun invert (fuzzyset)
  (case (eval fuzzyset)
        (VL VH)
        (L H)
        (ML MH)
        (MH ML)
        (H L)
        (VH VL)))

;; Weights fuzzy sets based on the importance of that
;; attribute or subfactor.

(defun weightVars (fuzzyset weight)
  (cond ((listp (car fuzzyset))
         (dotimes (I (length fuzzyset))
           (weightVars (nth I fuzzyset) weight)))
        (t (setf (car fuzzyset)
           (* weight (car fuzzyset)))))
  fuzzyset)

;; Performa the fuzzy union operation on a list of
;; fuzzy sets.

(defun fuzzyUnion (list)
  (setf tempSet (first list))
  (dotimes (I (length list))
    (dotimes (J (length (first list)))
      (setf (car (nth J tempSet))
            (max (car (nth J tempSet))
            (car (nth J (nth I list)))))))
  tempSet)
```

```lisp
;; The following three functions perform the defuzzification
;; operation, using the Center of Sums method.

(defun multSetPairs (set)
  (cond ((eq nil (cdr set))
          (* (caar set) (cadar set)))
         (t (+ (* (caar set) (cadar set))
           (multSetPairs (cdr set))))))

(defun addSet (set)
  (cond ((eq nil (cdr set))
          (caar set))
         (t (+ (caar set) (addSet (cdr set))))))

(defun defuzzify (set)
  (setf temp (addSet set))
  (cond ((equal temp 0.0)
          (setf temp 0.00001)))
  (/ (/ (multSetPairs set) temp) 10))

;; Variable that holds the final value that is
;; output by the program.

(defvar finalOutput nil)



;; The following are lists of subfactors for the
;; attributes used by the program. The lists contain
;; the subfactor name, placeholder for the subfactor
;; weight, placeholder for the subfactor linguistic value,
;; and n or p, based on whether the subfactor has a positive
;; or negative affect on performance.

(setf attentionList
      '(("Workload"                    nil nil n)
        ("Threat level"                nil nil p)
        ("Positive Crew Interaction"   nil nil p)
        ("Personal Stress"             nil nil n)))
(setf distractionList
      '(("Operational Intensity"       nil nil n)
        ("Threat level"                nil nil n)
        ("System Failure Probability"  nil nil n)
        ("Negative Crew Interaction"   nil nil n)
        ("Combat Experience"           nil nil p)
        ("Combat Training"             nil nil p)
        ("Extraneous Distractions"     nil nil n)))
```

```
(setf workloadList
      '(("Number of Systems"          nil nil n)
        ("System Training Level"      nil nil p)
        ("System Experience Level"    nil nil p)
        ("System Failure Probability" nil nil n)))
(setf phystressList
      '(("Operation Length"            nil nil n)
        ("Operational Intensity"       nil nil n)
        ("System Operation Difficulty" nil nil n)
        ("Health"                      nil nil p)
        ("Food / Water"                nil nil p)
        ("Environment"                 nil nil p)
        ("Protective Clothing Level"   nil nil n)
        ("Sleep Prior to Mission"      nil nil p)
        ("Current Sleep"               nil nil p)))
(setf mentalstressList
      '(("Threat Level"                nil nil n)
        ("System Training Level"       nil nil p)
        ("System Experience Level"     nil nil p)
        ("Command Level"               nil nil n)
        ("Time Available"              nil nil p)
        ("System Failure Probability"  nil nil n)
        ("Personal Stress"             nil nil n)))
(setf vigilanceList
      '(("Operation Length"       nil nil n)
        ("Distraction Level"      nil nil n)
        ("Sleep Prior to Mission" nil nil p)
        ("Current Sleep"          nil nil p)))
```

```
;; List of attributes used by this program.

(setf attributeList
      '(("Attention Level"              nil nil p)
        ("Distraction Level"            nil nil n)
        ("Workload"                     nil nil n )
        ("Physical Stress and Fatigue" nil nil n)
        ("Mental Stress"                nil nil n)
        ("Vigilance Level"              nil nil p)))

;; List of sttribute variables attached to subfactors
;; defined above.

(defvar masterList
      '(attentionList distractionList
        workloadList phystressList
        mentalstressList vigilanceList))

;; Following function searches list of subfactors and
;; returns the number of subfactors not set and the remaining
;; part of 1.0 not accounted for by the weights of the
;; subfactors already set.

(defun searchList (setList)
  (let ((temp1 1.0)
        (temp2 0)
        (temp3 setList))
        (dotimes (I (length temp3))
           (cond ((eq nil (second (nth I temp3)))
                  (setf temp2 (1+ temp2)))
                 (t (setf temp1(- temp1 (second (nth I temp3)))))))
      (cond ((<= temp1 0.0)  (setf temp1 0.00001)))
  (list temp1 temp2)))
```

```
;; Function used to normalize weights to 1.0.

(defun normalizeSets ()
  (let ((temp1 0)
        (temp2 0))
        (dotimes (I (length attributeList))
           (setf temp1 (+ temp1 (second (nth I attributeList)))))
        (dotimes (I (length attributeList))
          (setf (second (nth I attributeList)) (/ (second (nth I attributeList)) (temp1)))
          (dotimes (J (length (nth I masterList)))
             (setf temp2  (+ temp2  (second (nth J (nth I masterList))))))
          (dotimes (J (length (nth I masterList)))
             (setf (second (nth J (nth I masterList)))
                   (/ (second (nth J (nth I masterList))) temp2)))
          (setf temp2 0))))

;; Following function sets values of attributes and subfactors
;; after their entry by the program user.

(defun setValues (attrList attrSet &optional x1 x2)
  (cond ((eq x1 nil) (setf temp (searchList attrList))
           (cond ((eq (second temp) 0) (setf (second attrSet) 0.00001))
                 (t (setf (second attrSet) (/ (first temp)(second temp)))))
           (setf (third attrSet) M))
         ((numberp x1) (setf (second attrSet) x1)
          (cond ((eq nil x2) (setf (third attrSet) M))
                (t (cond ((eq (car (last attrSet)) p) (setf (third attrSet) x2))
                         (t (setf (third attrSet) (invert x2)))))))
         (t (cond ((eq nil x2) (setf temp (searchList attrList))
                    (cond ((eq (second temp) 0)  (setf (second attrSet) 0.00001))
                          (t (setf (second attrSet) (/ (first temp) (second temp))))))
                   (t (setf (second attrSet) x2)))
              (cond ((eq (car (last attrSet)) p) (setf (third attrSet) x1))
                    (t (setf (third attrSet) (invert x1)))))))
```

;; Function that computes the final output value of the program.

```
(defun computeFinalOutput (w)
  (let ((tempset1 nil)
        (tempset2 ()))
        (dotimes (I (length masterList))
          (cond ((not (eq (second (searchList (nth I masterList))) 0))
                    (cond ((eq (second (nth I attributeList))  nil)
                              (setValues attributeList (nth I attributeList))))
                    (setf tempset1 (weightVars (initVars (third (nth I attributeList)))
                                                              (second (nth I attributeList))))
                    (cond ((eq tempset2 nil) (setf tempset2 (list tempset1)))
                            (t (setf tempset2 (append (list tempset1) tempset2)))))
                  (t (dotimes (J (length (nth I masterList)))
                        (cond ((eq tempset1 nil) (setf tempset1(weightVars
                                                           (initVars (third (nth J  (nth I masterList))))
                                                                 (second (nth J (nth I masterList))))))
                                (t (setf tempset1(fuzzyUnion (list tempset1 (weightVars
                                                           (initVars (third (nth J (nth I masterList))))
                                                                second (nth J (nth I masterList)))))))))
                    (cond ((eq (second (nth I attributeList)) nil)
                              (setValues attributeList (nth I attributeList))))
                    (setf tempset1(weightVars tempset1(second (nth I attributeList))))
                    (cond ((eq tempset2 nil) (setf tempset2 (list tempset1)))
                              (t (setf tempset2 (append (list tempset1) tempset2))))))))
        (setf tempset2 (fuzzyUnion tempset2))
        (setf (window-stream-x-position w) (+ *x-origin* 250))
        (setf (window-stream-y-position w) (+ *y-origin* 200))
        (format w "FINAL OUTPUT => ~S~%" (defuzzify tempset2))))
```

```
;; The following functions and variables make up the
;; simple menu system used in this prototype program to
;; obtain input from the users of program.

;; required for use of Allegro Common LISP screen functions.

(require :xcw)
(use-package :cw)
(cw:initialize-common-windows :force t)

; dimensions for x-y coord system (window size auto adjusts).
(setf *x-origin*  75)
(setf *x-length*  600)
(setf *y-origin*  75)
(setf *y-length*  400)

;; Set of acceptable linguistic variable inputs.

(setf Lset '(VL vl L l ML ml M m MH mh H h VH vh))

;; The following three functions display current values
;; for final output variable, attributes, and subfactors.

(defun finalDisplay (w)
  (setf (window-stream-x-position w) (+ *x-origin* 250))
  (setf (window-stream-y-position w) (+ *y-origin* 200))
  (format w "Final Output = ~F~%" finalOutput))

(defun attributeDisplay (w)
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 100))
  (dotimes (I (length attributeList))
    (format w "~S" (first (nth I attributeList)))
    (setf (window-stream-x-position w) (+ *x-origin* 400))
    (format w "~S  ~S~%" (second (nth I attributeList)) (third (nth I attributeList)))
    (setf (window-stream-y-position w) (+ *y-origin* (- 85 (* I 15))))
    (setf (window-stream-x-position w) (+ *x-origin* 125))))
```

```
(defun subfactorDisplay (subfactorList w)
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 100))
  (dotimes (I (length subfactorList))
    (format w "~S" (first (nth I subfactorList)))
    (setf (window-stream-x-position w) (+ *x-origin* 400))
    (format w "~S  ~S~%" (second (nth I subfactorList)) (third (nth I subfactorList)))
    (setf (window-stream-y-position w) (+ *y-origin* (- 85 (* I 15))))
    (setf (window-stream-x-position w) (+ *x-origin* 125))))

;; The following function is used for simple input error detection.

(defun error1 (type w)
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 50))
  (setf (window-stream-foreground-color w) red)
  (case type (1 (format w "Error in entered numeric value.~%")
                 (setf (window-stream-y-position w) (+ *y-origin* 35))
                 (setf (window-stream-x-position w) (+ *x-origin* 125))
                (format w "Press any key to return to menu.~%")
                (setf (window-stream-y-position w) (+ *y-origin* 20))
                (setf (window-stream-x-position w) (+ *x-origin* 150))
                (read-char w)
             (2 (format w "Error in entered linguistic value.~%")
                (setf (window-stream-y-position w) (+ *y-origin* 35))
                (setf (window-stream-x-position w) (+ *x-origin* 125))
                (format w "Press any key to return to menu.~%")
                (setf (window-stream-y-position w) (+ *y-origin* 20))
                (setf (window-stream-x-position w) (+ *x-origin* 150))
                (read-char w)))
  (setf (window-stream-foreground-color w) black))
```

```lisp
;; Function converts string representation of input to
;; list representation.

(defun string-to-list (inString)
  (let ((tempList ())
       (tempList2 ())
       (temp inString))
       (cond ((equal temp "") ())
             (t (setf tempList (multiple-value-list (read-from-string temp)))
               (setf tempList2 (append tempList2 (list (first tempList))
                                       (string-to-list (subseq temp (second tempList)))))))))

;; Function controls menu for input of final output directly from user.

(defun finalMenu (w)
  (clear w)
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 275))
  (format w "Final Output Menu~%")
  (setf (window-stream-y-position w) (+ *y-origin* 260))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (format w "1. Enter Final Output as Numeric Value~%")
  (setf (window-stream-y-position w) (+ *y-origin* 245))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (format w "2. Enter Final Output as Linguistic Value~%")
  (setf (window-stream-y-position w) (+ *y-origin* 230))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (format w "A. Return to Top Menu~%")
  (setf (window-stream-y-position w) (+ *y-origin* 215))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf temp (car (string-to-list (read-line w))))
  (case temp (1 (clear w)
                (setf (window-stream-x-position w) (+ *x-origin* 125))
                (setf (window-stream-y-position w) (+ *y-origin* 275))
                (format w "Enter Final Output Numeric Value~%")
                (setf (window-stream-x-position w) (+ *x-origin* 125))
                (setf (window-stream-y-position w) (+ *y-origin* 260))
                (format w "(Value must be in the range 0.0 to 1.0)~%")
                (setf (window-stream-x-position w) (+ *x-origin* 150))
                (setf (window-stream-y-position w) (+ *y-origin* 245))
                (setq finalOutput (read w))
                (cond ((or (> finalOutput 1.0) (< finalOutput 0.0))
                       (error1 1 w)
                       (finalMenu w)))
                (clear w)
                (setf (window-stream-x-position w) (+ *x-origin* 125))
                (setf (window-stream-y-position w) (+ *y-origin* 150))
                (format w "Final Output = ~S~%" finalOutput))
```

```
 (2 (clear w)
    (setf (window-stream-x-position w) (+ *x-origin* 125))
    (setf (window-stream-y-position w) (+ *y-origin* 275))
    (format w "Enter Final Output Linguistic Value~%")
    (setf (window-stream-x-position w) (+ *x-origin* 125))
    (setf (window-stream-y-position w) (+ *y-origin* 260))
    (format w "(Value must be one of the following.)~%")
    (setf (window-stream-x-position w) (+ *x-origin* 125))
    (setf (window-stream-y-position w) (+ *y-origin* 245))
    (format w "(VL, L, ML, M, MH, H, VH)~%")
    (setf (window-stream-x-position w) (+ *x-origin* 150))
    (setf (window-stream-y-position w) (+ *y-origin* 230))
    (let ((temp1 nil))
         (setf temp1 (car (string-to-list (read-line w))))
         (cond ((not (member temp1 Lset))
                   (error1 2 w)
                   (finalMenu w))
                 (t (clear w)
                    (setf (window-stream-x-position w) (+ *x-origin* 250))
                    (setf (window-stream-y-position w) (+ *y-origin* 200))
                    (format t "~S~%" temp1)
                    (setf finalOutput (defuzzify (initVars (eval temp1))))
                    (format w "Final Output = ~S~%" finalOutput)))))
((or a A) (topMenu w))))
```

```
;; Function that controls attribute or subfactor selection. User can chose to enter attribute
;; weights and/or linguistic values or to continue to the subfactor menus.

(defun attrMenu (w)
  (clear w)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 275))
  (format w "Attribute Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 260))
  (format w "1. Set Attribute weights and/or values~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 245))
  (format w "2. Set Subfactor weights and/or values~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 230))
  (format w "A. Return to Top Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 215))
  (setf temp (read w))
  (case temp (1 (clear w)
                (attrWghtsMenu w))
             (2 (clear w)
                (subfactorWghtsMenu w))
             ((or a A) (topMenu w))))
```

```
;; Function to print out standard message of instructions for entering inputs.

(defun inputMessage (ycoord w)
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* ycoord))
  (format w "Enter importance as a decimal percentage, e.g., .34.,~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 15)))
  (format w "and the linguistic variable in upper or lower case,~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 30)))
  (format w "e.g., VL or l or Ml or m or h or vH.~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 45)))
  (format w "Either or both entries may be omitted if default~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 60)))
  (format w "settings are desired.~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf  (window-stream-y-position w) (+ *y-origin* (- ycoord  75)))
  (format w "Default importance is a percentage based on the total~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 90)))
  (format w "number of nil-set attributes.~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 105)))
  (format w "The linguistic variable value defaults to M<edium>.~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 120)))
  (setf (window-stream-foreground-color w) green)
  (format w "Example => '0.33 vl' or 'VH' or '0.2'~%")
  (setf (window-stream-foreground-color w) black)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* (- ycoord 140))))
```

;; Function that allows user to chose the particular attribute to enter.

```
(defun attrWghtsMenu (w)
  (clear w)
  (setq temp nil)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 275))
  (format w "Attribute Weights and/or Values Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 260))
  (dotimes (I (length attributeList))
    (format w "~S. ~S~%" (1+ I) (first (nth I attributeList)))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* (- 245 (* I 15)))))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (- (window-stream-y-position w) 15))
  (format w "A. Return to Previous Menu~%")
  (attributeDisplay w)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 150))
  (setq temp (car (string-to-list (read-line w))))
  (cond ((or (eq temp 'A) (eq temp 'a))
         (attrMenu w))
        (t (clear w)
          (setf (window-stream-x-position w) (+ *x-origin* 125))
          (setf (window-stream-y-position w) (+ *y-origin* 275))
          (format w "Enter importance of ~S attribute~%"
                                                    (first (nth (1- temp) attributeList)))
          (setf (window-stream-x-position w) (+ *x-origin* 125))
          (setf (window-stream-y-position w) (+ *y-origin* 260))
          (format w "in overall acquisition performance followed by linguistic~%")
          (setf (window-stream-x-position w) (+ *x-origin* 125))
          (setf (window-stream-y-position w) (+ *y-origin* 245))
          (format w "variable value of the attribute.~%")
          (inputMessage 230 w)
          (setf temp1 (string-to-list (read-line w)))
          (cond ((listp temp1)
                 (cond ((eq (second temp1) nil)
                        (setValues attributeList (nth (1- temp) attributeList) (first temp1)))
                       (t (setValues attributeList (nth (1- temp) attributeList)
                                                    (first temp1) (second temp1)))))
                (t (setValues attributeList (nth (1- temp) attributeList))))
          (attrWghtsMenu w))))
```

;; Function for chosing the particular subfactor to enter after attribute is chosen.

```
(defun subMenu (subListNum w)
  (clear w)
  (subfactorDisplay (nth subListNum masterList) w)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 275))
  (format w "Subfactor Menu for ~S attribute.~%" (first (nth subListNum attributeList)))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 260))
  (dotimes (I (length (nth subListNum masterList)))
     (format w "~S. ~S~%" (1+ I) (first (nth I (nth subListNum masterList))))
     (setf (window-stream-x-position w) (+ *x-origin* 125))
     (setf (window-stream-y-position w) (+ *y-origin* (- 245 (* I 15)))))
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (- (window-stream-y-position w) 15))
  (format w "A. Return to Previous Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (- (window-stream-y-position w) 15))
  (setq temp (read w))
  (cond ((or (eq temp 'A) (eq temp 'a)) (subfactorWghtsMenu w))
        (t (clear w)
           (subfactorDisplay (nth subListNum masterList) w)
           (setf (window-stream-x-position w) (+ *x-origin* 125))
           (setf (window-stream-y-position w) (+ *y-origin* 300))
           (format w "Enter importance of ~S subfactor~%" (first (nth (1- temp)
                                                    (nth subListNum masterList))))
           (setf (window-stream-x-position w) (+ *x-origin* 125))
           (setf (window-stream-y-position w) (+ *y-origin* 285))
           (format w "in ~S attribute, followed by~%"
                                         (first (nth subListNum attributeList)))
           (setf (window-stream-x-position w) (+ *x-origin* 125))
           (setf (window-stream-y-position w) (+ *y-origin* 270))
           (format w "the linguistic variable value of the subfactor.~%")
          (inputMessage 230 w)
          (setf temp1 (string-to-list (read-line w)))
          (cond ((listp temp1)
                 (cond ((eq (second temp1) nil) (setValues (nth subListNum masterList)
                                         (nth (1- temp) (nth subListNum masterList))
                                                                  (first temp1)))
                       (t (setValues (nth subListNum masterList)
                                         (nth (1- temp) (nth subListNum masterList))
                                                    (first temp1) (second temp1)))))
                (t (setValues (nth subListNum masterList)
                                      (nth (1- temp) (nth subListNum MasterList)))))
   (subMenu subListNum w))))
```

```lisp
;; Function that allows user to chose particular attribute whose subfactors are to be
;; entered by the user.

(defun subfactorWghtsMenu (w)
   (clear w)
   (setf (window-stream-x-position w) (+ *x-origin* 150))
   (setf (window-stream-y-position w) (+ *y-origin* 275))
   (format w "Subfactor Weights and/or Values Menu~%")
   (setf (window-stream-x-position w) (+ *x-origin* 125))
   (setf (window-stream-y-position w) (+ *y-origin* 260))
   (dotimes (I (length attributeList))
      (format w "~S. ~S Subfactors~%" (1+ I) (first (nth I attributeList)))
      (setf (window-stream-x-position w) (+ *x-origin* 125))
      (setf (window-stream-y-position w) (+ *y-origin* (- 245 (* I 15)))))
   (setf (window-stream-x-position w) (+ *x-origin* 125))
   (setf (window-stream-y-position w) (- (window-stream-y-position w) 15))
   (format w "A. Return to Previous Menu~%")
   (setf (window-stream-x-position w) (+ *x-origin* 150))
   (setf (window-stream-y-position w) (+ *y-origin* 100))
   (setq temp (car (string-to-list (read-line w))))
   (cond ((or (eq temp 'A) (eq temp 'a))
              (attrMenu w))
            (t (clear w)
               (subfactorDisplay (nth (1- temp) masterList) w)
               (subMenu (1- temp) w))))
```

```
;; Function that calls initialization functions for the fuzzy logic program, sets up
;; the display window, and starts the menuing system.

(defun startMenu ()
  (initSets)
  (setf *display*
    (make-window-stream
      :left 1
      :bottom 1
      :width (+ *x-length* (* 2 *x-origin*))
      :height (+ *y-length* (* 2 *y-origin*))
      :background-color white
      :foreground-color black
      :inner-region-left
      :inner-region-bottom
      :inner-region-width
      :inner-region-height
      :title "Fuzzy Human Factors Program"
      :activate-p t))
  (setf font1 (open-font :times :plain 16))
  (topMenu *display*))
```

```
;; Function that allows the user to chose entry of a final output directly or
;; allows the user to proceed to the attribute and subfactor menus.

(defun topMenu (w)
  (clear w)
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 275))
  (format w "TOP MENU~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 260))
  (format w "1. Final Output Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 245))
  (format w "2. Attribute Menu~%")
  (setf (window-stream-x-position w) (+ *x-origin* 125))
  (setf (window-stream-y-position w) (+ *y-origin* 230))
  (format w "A. Exit and Compute Final Output~%")
  (setf (window-stream-x-position w) (+ *x-origin* 150))
  (setf (window-stream-y-position w) (+ *y-origin* 215))
  (setq temp (read w))
  (case temp (1 (clear w)
                (finalMenu w))
             (2 (clear w)
                (attrMenu w))
             ((or a A) (clear w)
                (computeFinalOutput w))))
```

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